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VOC (Volatile Organic Compounds) Emissions Reduction Study for Oxidant Attainment in Massachusetts, Rhode Island, and Connecticut

Pacific Environmental Services, Inc., Santa Monica, CA

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A review was conducted of available models which relate ozone concentrations to VOC and NO_x emissions. The city-specific version of the Empirical Kinetic Modeling Approach (EKMA) was recommended as the most appropriate model for New England with reasonable input and computer requirements. This model was applied to Bridgeport-New Haven, CT; Providence, RI; Boston, MA; Springfield, MA; and Worcester, MA to compute VOC emission reductions necessary to achieve current and future Federal Oxidant Standards. The ozone design values and transported ozone values were selected to reflect the maximum requirement for VOC emission reduction. All O_3 monitoring data for Massachusetts, Connecticut and Rhode Island were adjusted to a common basis by taking into account EPA calibration audits and changes in calibration procedures.

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VOC EMISSIONS REDUCTION STUDY FOR OXIDANT ATTAINMENT IN MASSACHUSETTS, RHODE ISLAND, AND CONNECTICUT

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1.0 INTRODUCTION

Air quality data from Massachusetts, Rhode Island, and Connecticut have shown violations of the current Federal 1-hour averaged oxidant standard of 160 $\mu g/m^3$ (0.08 ppm). In order to meet the requirements of the Clean Air Act Amendments of 1977, the states must regulate emissions of volatile organic compounds (VOC) or oxides of nitrogen (NO_x) in order to attain the Federal oxidant standard. Currently, the most effective technique is to reduce VOC emissions. Thus, appropriate methodology must be used to estimate the reduction of VOC emissions necessary to attain the current and future oxidant standards.

Pacific Environmental Services, Inc. (PES) was contracted by EPA Region I to provide assistance in estimating the VOC emission reductions necessary to attain the oxidant standard in Massachusetts, Rhode Island, and Connecticut. The scope of work was to review available models which relate ozone concentrations to VOC and NO_x emissions, to perform a quality assurance examination of ambient ozone monitoring data in southern New England, to apply an appropriate model to various geographic areas in New England, and to evaluate VOC emission control strategies based on the model results.

2.0 REVIEW OF AVAILABLE MODELS

A number of techniques have been developed for relating emissions of volatile organic compounds (VOC) and nitrogen oxides (NO_x) to ambient ozone concentrations. These techniques range from simple algebraic expressions to sophisticated photochemical air quality simulation models which require a large computer.

2.1 MODEL DESCRIPTIONS

The most simple models, rollback[1] and Appendix J,[2] consider only changes in VOC emissions in their application and ignore the important effects of NO_x emissions on photochemical oxidant formation. These models are very simple to use, but are not sound theoretically. Rollback assumes a completely linear relationship between ozone concentrations and VOC emissions, while Appendix J uses an empirically-derived curve of maximum O_3 concentrations. In particular, EPA has recommended that Appendix J, due to its technical limitations, not be used for oxidant control strategy evaluations.[3]

The Empirical Kinetic Modeling Approach (EKMA)[4] does consider the effects of both VOC and NO_x emissions on ozone concentrations and treats the chemistry of photochemical smog formation in some detail. Thus, EKMA is theoretically more sound than rollback or Appendix J. The standard EKMA technique involves the use of a set of maximum ozone isopleths (based on Los Angeles parameters), as shown in Figure 2-1. These standard ozone isopleths are used in a nomographic procedure to estimate VOC (or NO_x) emission reductions, and thus the standard EKMA technique is fairly simple to use.

However, the standard EKMA method cannot incorporate local emissions or meteorological conditions and can treat the problem

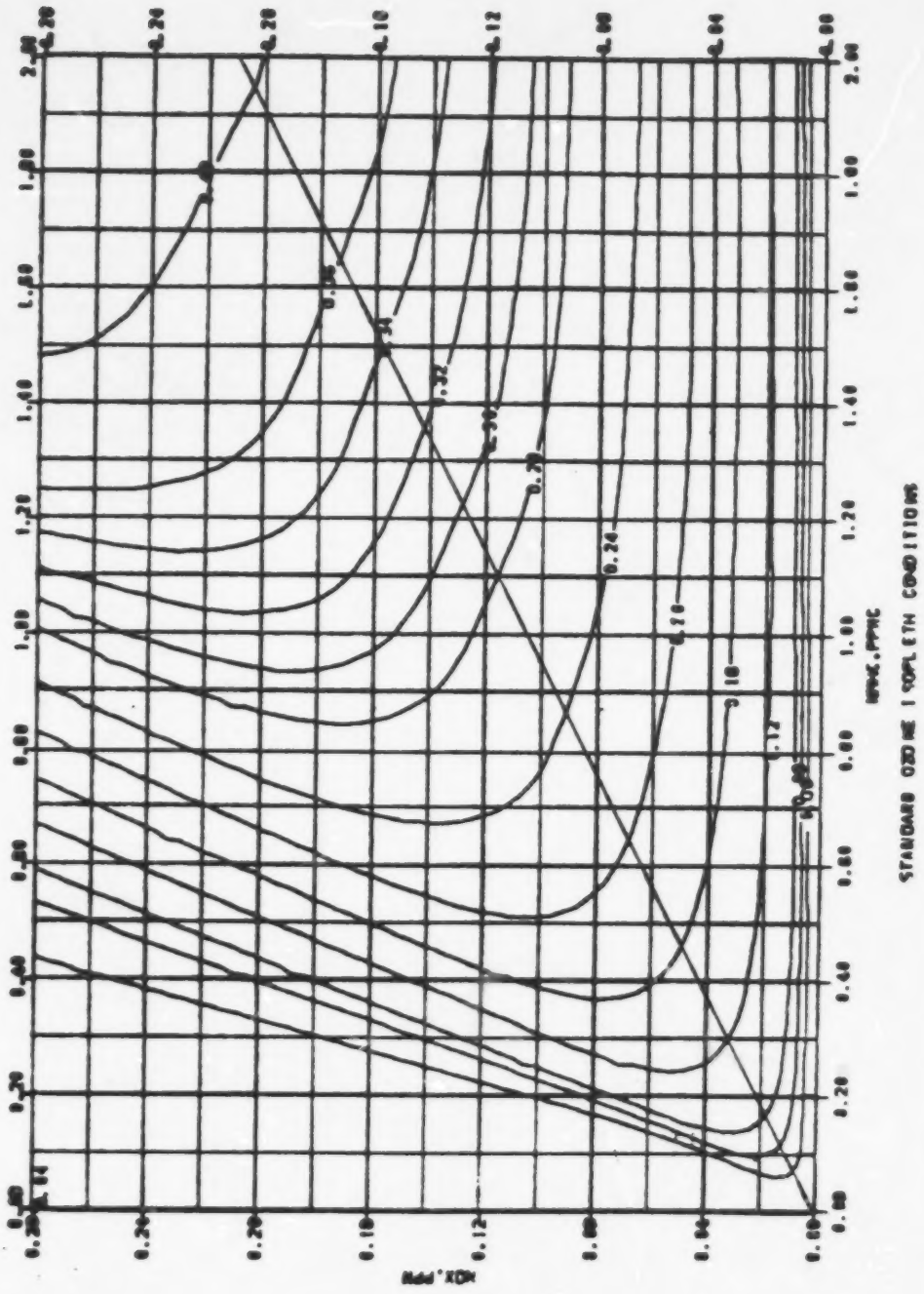

Figure 2-1.

of ozone transport only in a superficial manner. To overcome these difficulties, a city-specific version[5] of EKMA has been developed which can explicitly incorporate ozone and precursor transport (both surface and aloft), local light intensity and mixing height values, and (to a limited extent) local VOC and NO_x emissions. The local parameters are input into a computer program which produces a set of maximum ozone isopleths that are specific to the region of interest. These city-specific ozone isopleths are then used in a nomographic manner, similar to the standard EKMA technique, to estimate VOC (or NO_x) emission reductions necessary to attain the ambient oxidant standard. The input requirements of the city-specific EKMA technique are described in Table 2-1.

The most sophisticated photochemical air quality simulation models numerically solve fundamental conservation-of-mass equations and simulate chemistry, emissions, and atmospheric transport processes with detailed spatial and temporal resolution. These models are considered the most theoretically sound for prediction of ozone concentrations. However, these photochemical models require emissions, meteorological, and air quality data with considerable spatial and temporal resolution, and may have extensive computer storage and running time requirements. The spatial resolution required is typically 1 km x 1 km, and the temporal resolution required is hourly.

There are two major types of photochemical models: Lagrangian and Eulerian. Lagrangian models (also known as "trajectory" models)[7-9] estimate the concentration of ozone and other chemical species within a specified parcel of air. These models "follow" a specific air parcel and estimate pollutant concentrations within the selected parcel during subsequent hours. The city-specific EKMA method can be considered as a simplified Lagrangian model with very coarse resolution of emissions.

Table 2-1.
INPUT REQUIREMENTS OF THE CITY SPECIFIC EKMA MODEL

Data Required	Values Used in Standard Isopleths	Source of City-Specific Value
Light intensity as defined by latitude, longitude, and day of year	34°N, 118°W June 21	Latitude and longitude are determined using a local map; day of year is based on times of highest measured O_3 data
Mixing height data	Dilution rate = 3%/hr	Local mixing height measurements or data from Holzworth[6]
Relative emission rates	Emission rates after 8 a.m. LDT are zero	Local emissions and meteorological data
Ozone concentration transported into city	0.0 ppm	Ambient measurements

Eularian models (also called "grid" models)[10-12] calculate pollutant concentrations at fixed locations in space at specified times. The concentrations estimated at each location result from interaction among emissions, chemical reactions, and transport and dilution introduced by prevailing meteorological conditions. Some Eulerian and Lagrangian models are capable of providing vertical (as well as horizontal) resolution of pollutant concentrations by using a vertical "stack" of grid cells.

2.2 RECOMMENDATION OF APPROPRIATE MODEL

Although the sophisticated photochemical air quality simulation models provide the most sound theoretical relationship between VOC and NO_x emissions and ambient ozone concentrations, the input requirements of such models would require extensive additional effort. For example, an emission inventory for every 1 km x 1 km square area in southern New England would probably be necessary. Also, the computer time and storage requirements would be extensive for running such a model for a large number of control strategy evaluations.

Ths most appropriate model with reasonable input and computer requirements is the city-specific version of the Empirical Kinetic Modeling Approach (EKMA). This model can incorporate local light intensity and mixing height parameters, and can explicitly treat the important problem of ozone transport. The city-specific EKMA technique can also be apecifically applied to different urban areas in southern New England.

3.0 QUALITY ASSURANCE REVIEW OF O_3 MONITORING DATA

Calibration techniques and existing audit results were reviewed to determine if ambient ozone data measured in Connecticut, Rhode Island, and Massachusetts were uniform and consistent during the years 1975-1977. The ozone audit data were obtained from the EPA Region I Surveillance and Analysis Laboratory in North Lexington, Massachusetts. Data for 1975 were contained in a report "Ozone Transport Study" by Dr. Thomas M. Spittler.[13] Summaries of 1976 and 1977 audits were prepared for PES by the Surveillance and Analysis Laboratory.

The EPA Surveillance and Analysis Laboratory, Connecticut, and Rhode Island used the neutral-buffered KI (NBKI) calibration procedure throughout all three years, 1975-1977. In Massachusetts, the method of calibration was changed from NBKI to gas phase titration and UV photometry on July 1, 1975.

In order to adjust all O_3 monitoring data to a common basis, the EPA calibration audits for each monitoring station were averaged for each of the years 1975, 1976 and 1977. The results are shown in Table 3-1, along with the number of audits and state averages. Because of the change in calibration procedures in Massachusetts in 1975, the audits before and after July 1, 1975 were averaged and are reported separately in Table 3-1.

The EPA calibration audits in Table 3-1 were used to adjust O_3 monitoring data from Connecticut, Rhode Island, and Massachusetts to a common basis. Thus, all O_3 monitoring data were adjusted to the EPA NBKI calibration procedure. The adjustment was made according to the following formula:

$$\text{EPA } O_3 = \text{Station } O_3/(1 + 0.01\Delta\%)$$

where $\Delta\%$ is the average audit difference as shown in Table 3-1.

Table 3-1.
OZONE AUDITS 1975-1977 FOR SOUTHERN NEW ENGLAND
$\Delta\% = 100 \times (\text{Station } O_3 - \text{EPA } O_3)/\text{EPA } O_3$

Site	1975		1976		1977	
	No.	Ave. Δ%	No.	Ave. Δ%	No.	Ave. Δ%
Connecticut						
Bridgeport	0	---	2	- 9.2	2	+ 3.6
Derby	0	---	0	---	1	- 2.6
Eastford	3	+ 1.0	3	+ 7.0	0	---
Enfield	5	- 0.3	1	+ 4.2	0	---
Greenwich	0	---	3	- 6.8	1	- 3.1
Hamden	4	+ 2.5	3	+ 0.8	0	---
Hartford	0	---	4	- 1.1	1	+ 2.6
Middletown	4	+ 1.2	3	+ 3.3	2	- 0.4
New Haven	4	+ 3.6	5	- 0.1	2	- 0.5
Windsor	4	- 3.0	0	---	0	---
State Average		+ 0.83		- 0.24		- 0.07
Massachusetts						
Amherst	1; 2*	- 6.7; - 2.6*	1	- 6.8	2	-14.5
Ashland	0	---	2	- 3.1	0	---
Attleboro	0	---	1	- 8.0	0	---
Chicopee	0	---	1	+ 2.0	0	---
Danvers	0	---	0	---	1	- 4.8
Fairhaven	0	---	1	- 5.5	0	---
Framingham	1; 3*	- 8.5; -12.2*	2	-15.5	0	---
Medfield	0	---	3	-10.8	0	---
Medford	1; 3*	-10.5; -10.0*	4	-16.8	2	-13.5
Quincy	1; 3*	- 2.5; - 4.6*	4	- 5.1	0	---
Salem	1; 4*	- 4.0; -16.1*	2	-18.9	0	---
Worcester	1; 3*	- 8.4; -15.3*	1	- 9.2	2	-17.5
State Average		- 6.77; -10.13*		- 8.88		-12.58
Rhode Island						
Kent County	0	---	3	- 1.7	2	+ 0.7
Providence	5	-11.7	4	- 3.1	2	+ 2.1
Scituate	4	- 8.7	0	---	0	---
State Average		-10.20		- 2.40		+ 1.40

*First number refers to before July 1; second number refers to on or after July 1.

In 1978 results were published[14] showing the need for a change to a new reference procedure utilizing ultraviolet photometry, which shows significantly less variability and greater accuracy than the NBKI or gas phase titration (GPT) procedures. It was also noted that a manual procedure utilizing boric acid (BAKI) instead of the previous phosphate buffer (NBKI) also gave less bias and agreed well with UV photometry. The BAKI method was proposed as an interim reference standard, to be related to the UV standard whenever possible. Direct comparison of the new methods with the NBKI procedure used in EPA Region I showed that the NBKI results required a downward correction of 19 percent. This has accordingly been applied along with the adjustments given in Table 3-1 to all the monitored ozone values given in this report, starting with Tables 3-2 and 3-3.

The adjusted second-highest O_3 maxima for all monitoring stations during 1975-1977 in Massachusetts are presented in Table 3-2. Those for Connecticut and Rhode Island are shown in Table 3-3.

Table 3-2.
MASSACHUSETTS ADJUSTED O_3 VALUES ($\mu g/m^3$)
Second Highest Maxima by Station

Site	1975	1976	1977
Amherst	279	320	269
Ashland	-	295	178
Attleboro	-	290	237
Boston	168	-	-
Cambridge	264	-	-
Chicopee	203	292	-
Danvers	-	-	225
Fairhaven	296	327	-
Fall River	271	287	272
Fitchburg	230	296	-
Framingham	333	319	-
Greenfield	239	331	-
Lowell	215	275	-
Medfield	274	370	254
Medford	283	305	302
Needham	-	104	-
Pittsfield	291	240	227
Quincy	272	295	272
Salem	241	322	-
Springfield	140	-	-
Waltham (0003)	256	348	-
Waltham (0004)	252	-	-
West Newbury	149	348	382
Worcester	272	327	275

Table 3-3.
CONNECTICUT ADJUSTED O_3 VALUES ($\mu g/m^3$)
Second Highest Maxima by Station

Site	1975	1976	1977
Bridgeport	410	399	420
Danbury	359	371	420
Derby	-	446	527
Eastford	351	341	373
Enfield	279	332	360
Greenwich	364	408	360
Groton	292	353	411
Hamden	418	377	428
Hartford	299	343	394
Morris (Litchfield County)	244	310	309
Middletown	463	392	319
New Britain	70	-	-
New Haven (0008)	475	-	-
New Haven (0123)	-	373	530
Stamford	307	-	-
Torrington	299	-	-
Windsor	335	-	-

RHODE ISLAND ADJUSTED O_3 VALUES ($\mu g/m^3$)
Second Highest Maxima by Station

Site	1975	1976	1977
West Greenwich (Kent County)	-	323	299
Providence	296	287	303
Scituate	191	-	-

4.0 MODEL APPLICATION

The city-specific version of the Empirical Kinetic Modeling Approach (EKMA) was applied to the following five urban areas in southern New England:

1. Bridgeport-New Haven, Connecticut
2. Providence, Rhode Island
3. Boston, Massachusetts
4. Springfield, Massachusetts
5. Worcester, Massachusetts

For each of these areas, separate city-specific ozone isopleths were generated for both current and future O_3 transport. In addition, a general set of ozone isopleths appropriate to the New England area were generated, which can be used in the same manner as the standard EKMA isopleth curves.

4.1 METHODOLOGY

Because the southern New England area is heavily affected by O_3 transport from the New York City area,[15] the choice of an appropriate O_3 design value is not simple. The normal selection of the highest second-highest O_3 value may not result in the maximum reduction of VOC emissions necessary to attain the Federal oxidant standard, especially if the high O_3 values are due almost entirely to transport. For example, the highest second-highest O_3 value in the New England area during 1975-1977 was 530 $\mu g/m^3$ (0.274 ppm)* recorded in New Haven, Connecticut on July 16, 1977. However, since the wind was from the southwest, this high value was probably caused almost entirely by transport from the New York City area.

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* Unless otherwise noted, all reported O_3 concentrations have been adjusted according to the EPA calibration audits in Table 3-1 and also for the new reference procedure as discussed on the previous page. O_3 concentrations in $\mu g/m^3$ can be converted to ppm by dividing by 1960.

The methodology used in all five urban areas which were studied was to examine the conditions which would result in the highest second-highest O_3 design value after consideration of transport. Specifically, the maximum values of the quantity (D-AT) were determined, where D is the receptor O_3 design value, T is the transported O_3 value, and A is the additivity factor, assumed to be 0.45. This approach, in the standard EKMA application, would result in the maximum reduction of VOC emissions necessary to attain the Federal oxidant standard.

To determine the locations of the receptor and transport sites, trajectory analysis was conducted which considered both resultant wind data and hourly ambient ozone concentration data. In general, a high-ozone trajectory was traced along the network of ambient monitoring stations; the location of incoming transported O_3 data did not logically correspond were eliminated from consideration.

4.2 BRIDGEPORT-NEW HAVEN, CONNECTICUT

The date of the second-highest value of (D-AT) for the Bridgeport-New Haven urban area was May 24, 1977, with Eastford, Connecticut as the receptor area. Adjusted hourly O_3 data from May 24, 1977 are shown in Table 4-1; there is a clean tracing of a high-ozone trajectory from Bridgeport and New Haven through Middletown and towards Eastford. The relationship between the urban area and receptor area is shown in Figure 4-1.

The adjusted O_3 design value in Eastford was 0.190 ppm. The most obvious site for obtaining transported O_3 concentrations, Greenwich, recorded somewhat lower O_3 values than either Bridgeport or New Haven; it is possible that Greenwich is so close to the New York City urban area that the large NO emissions from the New York City area actually suppress ozone concentrations in Greenwich.

Table 4-1. ADJUSTED HOURLY O_3 DATA (ppm) FOR MAY 24, 1977

Station	07	08	09	10	11	12	13	14	15	16	17	18
Bridgeport, Conn.	.009	.016	.028	.035	.062	.108	.136	.098	.058	.026	.019	.014
Danbury, Conn.	.024	.041	.059	.066	.073	.089	.101	.109	.101	.117	.085	.049
Derby, Conn.	.017	.029	.045	.061	.062	.104	.137	.150	.117	.070	.036	.021
Eastford, Conn.	.016	.032	.065	.089	.105	.113	.124	.138	.150	.190	.190	.142
Enfield, Conn.	.015	-	.056	.091	.120	.125	.114	.109	.076	.070	.100	.110
Greenwich, Conn.	-	-	-	.083	.104	.113	.104	.092	.062	.033	.017	.008
Groton, Conn.	.020	.028	.045	.068	-	-	.116	.127	.101	.051	.041	.036
Hartford, Conn.	.015	.036	.059	-	-	.095	.099	.095	.101	.142	.118	.066
Morris, Conn.	.032	.052	.073	.082	.089	.097	.101	.097	.101	.109	.105	.077
Middletown, Conn.	.017	.023	-	.048	.053	.075	.100	.132	.119	.082	.049	.028
New Haven, Conn.	.000	.005	.015	.039	.061	.109	.154	.130	.078	.044	.032	.019
West Greenwich, Rhode Island	.008	.016	.016	-	.069	.069	.081	.113	.122	.089	.057	.036

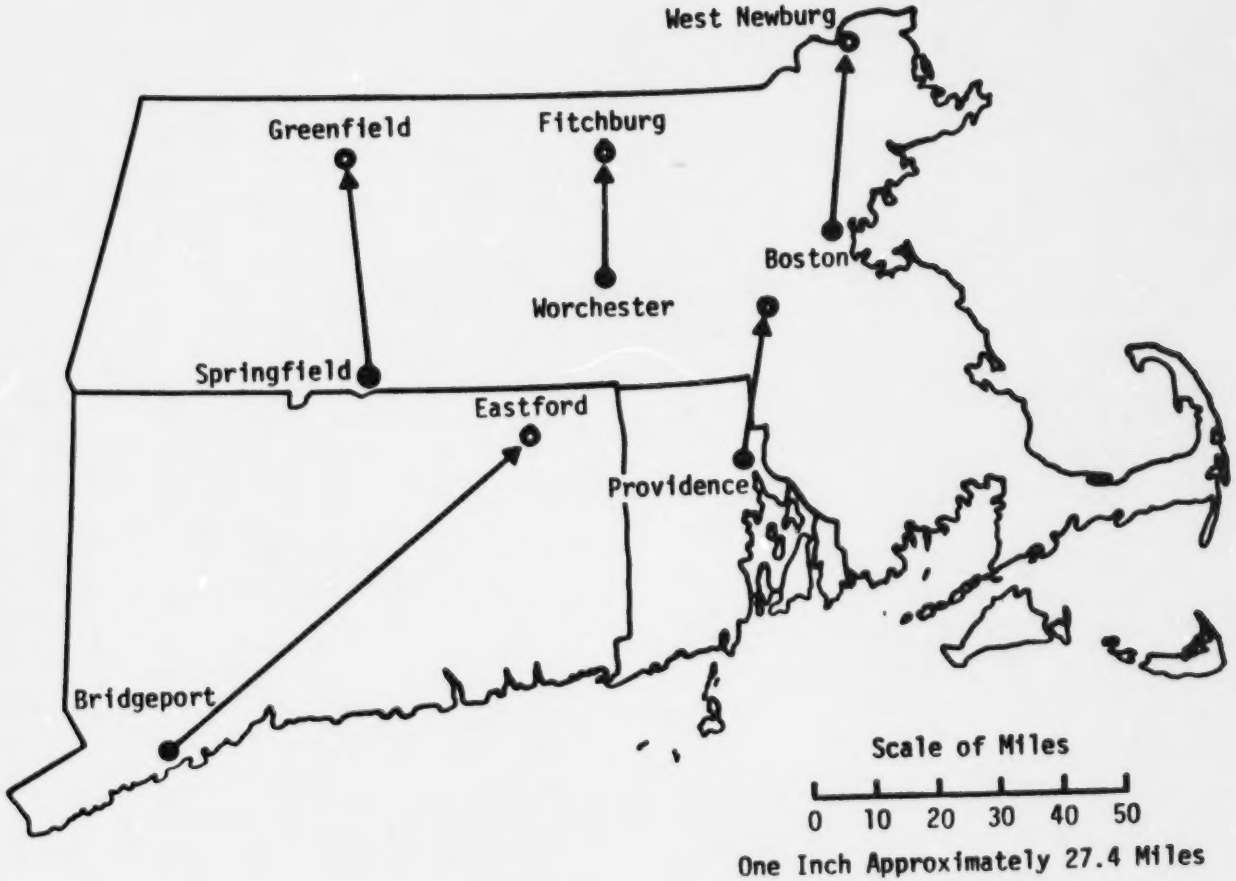


Figure 4-1. Relationships Between Urban and Receptor Areas

For a reasonable transported O_3 value, the maximum hourly O_3 concentration in the Bridgeport-New Haven-Derby area was used; this adjusted transported O_3 value was 0.154 ppm recorded in New Haven.

The parameters used to generate the city-specific EKMA ozone isopleths are shown in Table 4-2. The mixing heights were derived from the average summer morning and afternoon mixing heights in Holzworth[6] for the Bridgeport-New Haven area. Emission parameters were determined from countywide National Emission Data System (NEDS) data and using a diurnal traffic curve for the Boston area.[16] Only transport of ozone aloft was assumed; no surface transport or precursor transport was used in the generation of the city-specific isopleths.

It was assumed that the future transported O_3 concentration would be equal to the Federal ozone standard, thus maximizing the VOC emission reductions required. Four city-specific EKMA curves were run: (1) with current O_3 transport = 0.154 ppm, (2) with future O_3 transport = 0.08 ppm, (3) with future transport = 0.10 ppm, and (4) with future O_3 transport = 0.12 ppm. The resulting city-specific ozone isopleths are presented as Figures A-1 to A-4 in the Appendix.

4.3 PROVIDENCE, RHODE ISLAND

The date of the second-highest value of (D-AT) for the Providence urban area was July 20, 1976, with Medfield, Massachusetts as the receptor area. Adjusted hourly O_3 data from July 20, 1976 are shown in Table 4-3, and a high-ozone trajectory is indicated from West Greenwich, Rhode Island through Providence and towards Medfield. The relationship between the urban area and the receptor area is shown in Figure 4-1.

The adjusted O_3 design value in Medfield was 0.189 ppm. For a reasonable transport value, the highest O_3 value of 0.169 ppm

Table 4-2.
CITY-SPECIFIC EKMA PARAMETERS FOR BRIDGEPORT-NEW HAVEN

Urban Area: Bridgeport-New Haven, Connecticut

Latitude: 41° 15'N

Longitude: 73° 5'W

Date: May 24, 1977

Receptor Area: Eastford, Connecticut

O_3 Design Value: 0.190 ppm

O_3 Transport Aloft: 0.154 ppm

Mixing Heights: 700 m (0800) to 1,400 m (1,800)

Emissions:	8-9	9-10	10-11	11-12	12-13	13-18
NMHC	0.333	0.271	0.086	0.010	0.014	0
NO_x	0.333	0.271	0.101	0.011	0.010	0

Table 4-3. ADJUSTED HOURLY O_3 DATA (ppm) FOR JULY 20, 1976

Station	07	08	09	10	11	12	13	14	15	16	17	18
West Greenwich, Rhode Island	.041	.070	.087	.095	.099	.103	.120	.169	.140	.115	.095	.087
Providence, Rhode Island	.021	.042	.054	.071	.083	.087	.096	.117	.159	.126	.092	.079
Attleboro, Massachusetts	.040	.069	.087	.092	-	-	.105	.110	.152	.148	.110	.083
Ashland, Massachusetts	.044	.058	.063	-	.082	.087	.092	.100	.134	.182	.151	.111
Medfield, Massachusetts	.045	.075	.085	.087	.096	.107	.109	.119	.123	.207	.189	.145

recorded at West Greenwich was used. The parameters used to generate the city-specific EKMA ozone isopleths are shown in Table 4-4. Mixing heights were derived from Holzworth[6] and emissions were approximated as a Gaussian distribution using a Boston diurnal traffic curve.[16] Only transport of ozone aloft was assumed. Four cases were again run: current O_3 transport of 0.169 ppm, and 0.08, 0.10, and 0.12 ppm future O_3 transport. The resulting city-specific ozone isopleths are presented as Figures A-5 to A-8 in the Appendix.

4.4 BOSTON, MASSACHUSETTS

The date of the second-highest value of (D-AT) for the Boston urban area was August 26, 1976, with West Newbury, Massachusetts as the receptor area. Adjusted hourly O_3 data from August 26, 1976 are shown in Table 4-5, and a high-ozone trajectory is indicated from Medfield through Medford and Salem and towards West Newbury. The relationship between the urban area and the receptor area is shown in Figure 4-1.

The adjusted O_3 design value in West Newbury was 0.177 ppm. For a reasonable transport value, the high O_3 value of 0.099 ppm recorded at Medfield was used. The parameters used to generate the city-specific EKMA isopleths are shown in Table 4-6. Mixing heights were determined from Holzworth[6] and emissions were approximated as a Gaussian distribution using a Boston diurnal traffic curve. Only transport of ozone aloft was assumed. Four cases were again run: current O_3 transport of 0.099 ppm, and 0.08, 0.10, and 0.12 ppm future O_3 transport. The resulting city-specific isopleths are presented as Figures A-9 to A-12 in the Appendix.

Table 4-4.
CITY-SPECIFIC EKMA PARAMETERS FOR PROVIDENCE

Urban Area: Providence, Rhode Island

Latitude: 41° 50'N

Longitude: 71° 25'W

Date: July 20, 1976

Receptor Area: Medfield, Massachusetts

O_3 Design Value: 0.189 ppm

O_3 Transport Aloft: 0.169 ppm

Mixing Heights: 500 m (0800) to 1,200 m (1,800)

Emissions:	8-9	9-10	10-11	11-18
NMHC, NO_x	0.317	0.165	0.064	0

Table 4-5. ADJUSTED HOURLY O_3 DATA (ppm) FOR AUGUST 26, 1976

Station	07	08	09	10	11	12	13	14	15	16	17	18
Amherst, Mass.	.006	.013	.015	.039	-	-	.087	.120	.100	.074	.057	.050
Eastford, Conn.	.006	-	.041	.052	.057	.061	.064	.066	.066	.091	.093	.093
Ashland, Mass.	.001	.006	.022	-	.061	.078	.076	.079	.070	.059	.082	.075
Attleboro, Mass.	.004	.022	.053	.080	.088	.089	.105	.128	.099	.101	.111	.100
Chicopee, Mass.	.002	.008	-	.056	.083	.092	.073	.079	.075	.083	.079	.052
Fairhaven, Mass.	.025	.062	.073	.068	.079	.088	.086	.083	.086	.087	.054	.053
Fitchburg, Mass.	.007	.039	.053	.066	.088	.083	.066	.066	.071	.071	.089	.053
Greenfield, Mass.	.004	.011	.022	.049	.064	.080	-	.077	.111	.080	.049	.022
Lowell, Mass.	.007	.013	.027	.048	.075	.070	.070	.077	.140	.111	.069	.044
Medfield, Mass.	.003	.015	.041	.072	.088	.099	.093	.093	.091	.114	.111	.104
Medford, Mass.	.000	.010	.034	.073	.109	.156	.153	.151	.112	.103	.086	.049
Pittsfield, Mass.	.023	.020	.041	.055	.057	.062	.064	.062	.058	.055	.046	.039
Quincy, Mass.	.002	.012	.036	.055	-	.150	.125	.068	.084	.079	.066	.070
Salem, Mass.	.004	.040	.075	.125	.160	.175	.145	.117	.110	.100	.087	.073
Waltham, Mass.	.000	.006	.030	.052	.057	.065	.139	.127	.098	.074	.065	.069
West Newbury, Mass.	.009	.027	.045	.071	.093	.120	.177	.186	.120	.125	.120	.089
Worcester, Mass.	.002	.015	.045	.055	.062	.066	.062	.066	.074	.069	.055	.055

Table 4-6.
CITY-SPECIFIC EKMA PARAMETERS FOR BOSTON

Urban Area: Boston, Massachusetts

Latitude: 42° 22'N

Longitude: 71° 5'W

Date: August 26, 1976

Receptor Area: West Newbury, Massachusetts

O_3 Design Value: 0.117 ppm

O_3 Transport Aloft: 0.099 ppm

Mixing Heights: 450 m (0800) to 1,200 m (1,800)

Emissions:	8-9	9-10	10-11	11-18
NMHC, NO_x	0.317	0.165	0.064	0

4.5 SPRINGFIELD, MASSACHUSETTS

The date of the second-highest value of (D-AT) for the Springfield urban area was August 5, 1976, with Greenfield as the receptor area. Adjusted hourly O_3 data from August 5, 1976 are shown in Table 4-7, and a high-ozone trajectory is indicated from Enfield, Connecticut through Chicopee and Amherst towards Greenfield. The relationship between the urban area and the receptor area is shown in Figure 4-1.

The adjusted O_3 design value in Greenfield was 0.169 ppm. For a resonable transport value the high O_3 value of 0.126 ppm recorded in Enfield was used. The parameters used to generate the city-specific EKMA isopleths are shown in Table 4-8. Mixing heights were determined from Holzworth[6] and emissions were approximated as a Gaussian distribution using a Boston diurnal traffic curve. Only transport of ozone aloft was assumed. Four cases were again run: current O_3 transport of 0.126 ppm, and 0.08, 0.10, and 0.12 ppm future O_3 transport. The resulting city-specific isopleths are presented as Figures A-13 to A-16 in the Appendix.

4.6 WORCESTER, MASSACHUSETTS

The date of the second-highest value of (D-AT) for the Worcester urban area was July 27, 1976, with Fitchburg as the receptor area. Adjusted hourly O_3 data from July 27, 1976 are shown in Table 4-9, and a high-ozone trajectory is indicated from Eastford, Connecticut to Fitchburg. The relationship between the urban area and the receptor area is shown in Figure 4-1.

The adjusted O_3 design value in Fitchburg was 0.130 ppm. For a reasonable transport value, the high O_3 value of 0.125 ppm recorded in Eastford was used. The parameters used to generate the city-specific EKMA isopleths are shown in Table 4-10. Mixing

Table 4-7. ADJUSTED HOURLY O_3 DATA (ppm) FOR AUGUST 5, 1976

Station	07	08	09	10	11	12	13	14	15	16	17	18
Enfield, Conn.	.044	.050	.069	.087	.086	.079	.090	.096	.124	.126	.103	.095
Amherst, Mass.	.026	.052	.074	.096	.109	.106	.103	.111	.120	.126	.184	.156
Eastford, Conn.	.026	.021	.019	.017	.017	.017	.017	.017	.017	.017	.017	.013
Ashland, Mass.	.046	.064	.079	.080	.078	.076	.084	.094	.110	.119	.101	.096
Attleboro, Mass.	.051	.060	.078	.083	.088	.083	.082	.083	.082	.073	.064	.064
Chicopee, Mass.	.010	.040	.055	-	.097	.092	.096	.097	.101	.139	.139	.123
Fairhaven, Mass.	.069	.071	.071	.069	.073	.067	.064	.060	.056	.060	.064	.071
Fitchburg, Mass.	.049	.066	-	-	.066	.073	.083	.092	.100	.101	.122	.117
Greenfield, Mass.	.011	.027	.058	.093	.125	.107	.107	.109	.113	.129	.134	.169
Lowell, Mass.	.019	.037	.053	.062	.062	.066	.066	.071	.074	.075	.058	.075
Medford, Mass.	.023	.044	.068	.081	.068	.073	.076	.066	.074	.078	.066	.051
Pittsfield, Mass.	.021	.042	.064	.083	.088	.094	.093	.097	.109	.124	.122	.110
Quincy, Mass.	.044	.060	.092	.108	.098	.088	.083	.085	.083	.080	.073	.060
Salem, Mass.	.033	.065	.090	-	-	-	-	-	-	-	-	-
Waltham, Mass.	.036	.053	.084	.095	.085	.088	-	.088	.098	.100	.080	.067
West Newbury, Mass.	.036	.045	.080	.098	.089	.084	.093	.098	.107	.111	.116	.111
Worcester, Mass.	.023	.030	.043	.066	.066	.071	.075	.080	.086	.088	.087	.077

Table 4-8.
CITY SPECIFIC EKMA PARAMETERS FOR SPRINGFIELD

Urban Area: Springfield, Massachusetts

Latitude: 42° 5'N

Longitude: 72° 35'W

Date: August 5, 1976

Receptor Area: Greenfield, Massachusetts

O_3 Design Value: 0.169 ppm

O_3 Transport Aloft: 0.126 ppm

Mixing Heights: 500 m (0800) to 1,600 m (1,800)

Emissions:	8-9	9-10	10-11	11-18
NMHC, NO_x	0.317	0.165	0.064	0

Table 4-9. ADJUSTED HOURLY O_3 DATA (ppm) FOR JULY 27, 1976

Station	07	08	09	10	11	12	13	14	15	16	17	18
Amherst, Mass.	.031	.048	.070	.083	.092	.083	.087	.092	.096	.096	.092	.074
Eastford, Conn.	.034	.047	.064	.072	.087	.095	.113	.125	.122	.133	.113	.091
Ashland, Mass.	.054	.070	.078	.073	.070	.067	.064	.067	.071	.068	.067	.064
Attleboro, Mass.	.044	.058	.075	.083	.092	.097	.100	.079	.070	.073	.064	.062
Chicopee, Mass.	.032	.045	.067	.075	.083	.087	.096	.094	.097	.104	.109	.081
Danvers, Mass.	.041	.065	.091	.108	.109	.111	.109	.112	.121	.112	.105	.112
Fairhaven, Mass.	.041	.039	.043	.045	.047	.045	.039	.030	.030	.026	.024	.023
Fitchburg, Mass.	.054	.065	.083	.099	.100	.110	.121	.121	.130	.127	.130	.124
Greenfield, Mass.	.036	-	.066	.084	.102	.111	.102	.107	.111	.098	.080	.080
Lowell, Mass.	.020	.030	.045	.062	.075	.071	.076	.084	.084	.094	.088	.087
Medfield, Mass.	.072	.087	.100	.115	.126	.134	.139	.140	.146	.137	.145	.141
Medford, Mass.	.024	.042	.062	.076	.083	.092	.090	.092	.097	.093	.087	.096
Pittsfield, Mass.	.040	.061	.062	.074	.084	.092	.100	.101	.106	.087	.066	.053
Quincy, Mass.	.043	.062	.077	.091	.094	.097	.096	.099	.090	.076	.058	.049
Waltham, Mass.	.033	.061	.075	.102	.104	.116	.120	.125	.137	.129	.138	.129
West Newbury, Mass.	.036	.045	.058	.089	.102	.111	.111	.111	.120	.129	.138	.129
Worcester, Mass.	.023	.042	.062	.079	.093	.104	.106	.108	.121	.134	.134	.126

Table 4-10.

CITY-SPECIFIC EKMA PARAMETERS FOR WORCESTER

Urban Area: Worcester, Massachusetts

Latitude: 42° 15'N

Longitude: 71° 50' W

Date: July 17, 1976

Receptor Area: Fitchburg, Massachusetts

O_3 Design Value: 0.130 ppm

O_3 Transport Aloft: 0.125 ppm

Mixing Heights: 500 m (0800) to 1,400 m (1,800)

Emissions:	8-9	9-10	10-11	11-18
NMHC, NO_x	0.317	0.165	0.064	0

heights were determined from Holzworth[6] and emissions were approximated as a Gaussian distribution using a Boston diurnal traffic curve. Only transport of ozone aloft was assumed. Four cases were again run: current O_3 transport of 0.125 ppm, and 0.08, 0.10, and 0.12 ppm future O_3 transport. The resulting city-specific isopleths are presented as Figures A-17 to A-20 in the Appendix.

4.7 NEW ENGLAND STANDARD OZONE ISOPLETHS

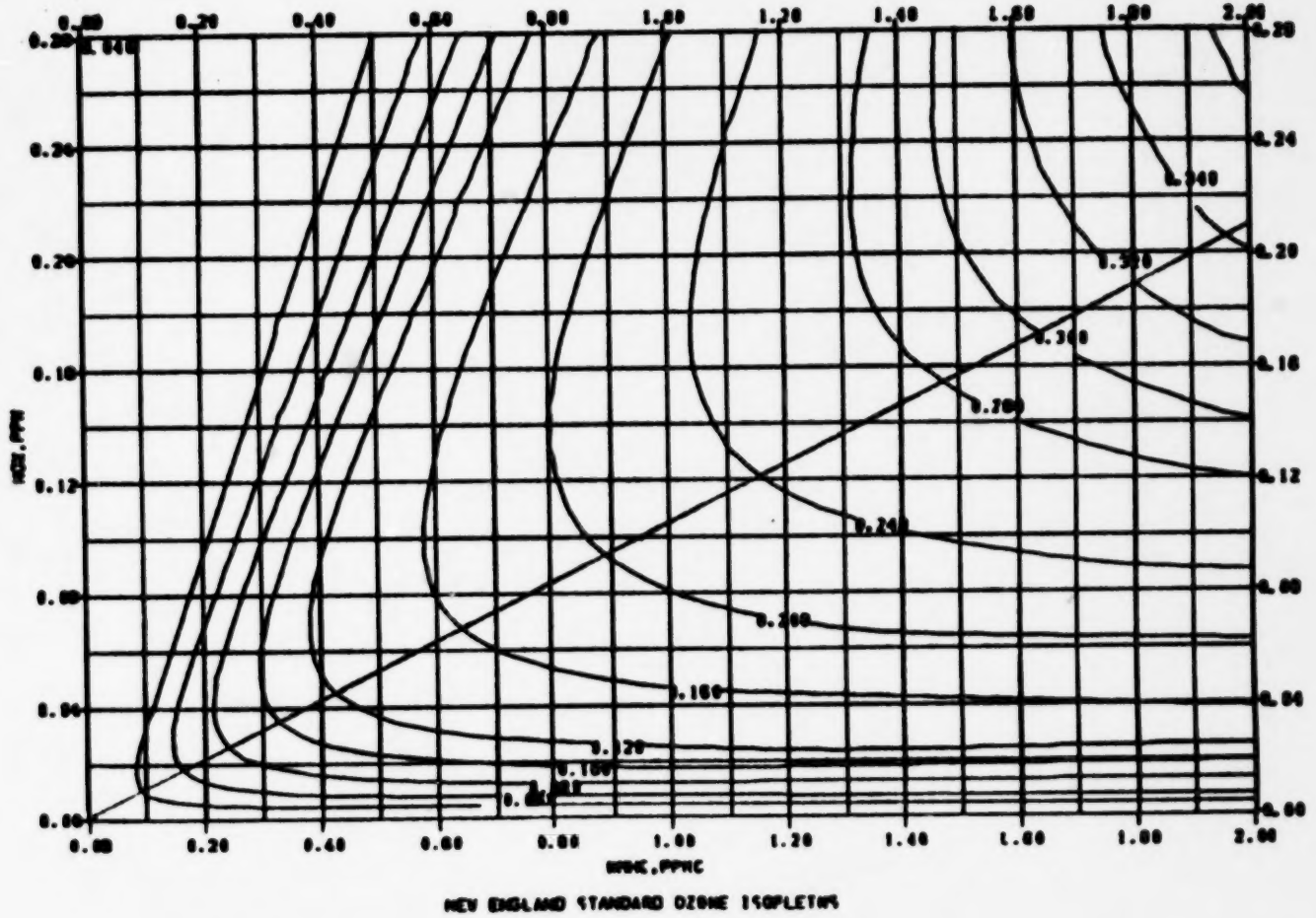
A general set of ozone isopleths, similar to the standard EKMA curves, were generated with light intensity and dilution parameters characteristic of the New England area. These New England standard isopleths can be used in exactly the same manner as the standard EKMA curves.

Two parameters were changed from the standard EKMA isopleths to calculate the New England standard isopleths:

1. The light intensity was calculated for 42° 22' N. latitude 71° 5' W. longitude (Boston) instead of 34° N., 118° W. (Los Angeles).

2. The dilution rate was increased to 7%/hour (i.e., doubling over 10 hours) compared to the standard EKMA value of 3%/hour.

All other parameters (e.g., zero emissions, zero transport) were identical to the standard EKMA curves. The New England standard ozone isopleths are shown in Figure 4-2.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0.80
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1.20
1.40
1.60
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0.12
0.08
0.04
0.00
0.360
0.280
0.240
0.200
0.160
0.120
0.080
NEW ENGLAND STANDARD OZONE ISOPLETHS

Figure 4-2

5.0 CONTROL STRATEGY EVALUATIONS

The city-specific EKMA ozone isopleths presented in the Appendix were used to estimate the VOC emission reductions necessary to achieve current and future Federal oxidant standards. A Summary of the locations and main parameters is presented in Table 5-1. Emission reduction calculations were made not only for the present Federal O_3 standard of 0.08 ppm, but also for the possible future O_3 standards of 0.10 ppm and 0.12 ppm. All calculations were made for a NMHC/NO_x ratio of 9.5:1. The results are presented in Table 5-2.

For comparison, the standard EKMA ozone isopleths, shown in Figure 3-1, and the New England standard ozone isopleths, shown in Figure 4-2, were also used to calculate VOC emission reductions, assuming an additivity factor of 0.45. It was assumed in all cases that the future O_3 transport would be equal to the O_3 standard, thus maximizing the VOC control required. Again, all calculations were made for a NMHC/NO_x ratio of 9.5:1. These results are also presented in Table 5-2.

As shown in Table 5-2, the differences between the three methods of calculating VOC emission reductions were relatively small. For the case of Worcester, Massachusetts the differences were slightly larger but still quite small. In this case, the O_3 design value was essentially equal to the O_3 transport value, and it is possible that the transport additivity factor of 0.45 used in the standard and New England EKMA analyses may not be accurate.

In all cases, because of the ability of the city-specific EKMA model to explicitly treat O_3 transport and local light intensity, emissions and meteorology, the VOC emission reductions calculated by the city-specific EKMA method should be regarded as the most accurate values for attainment of the Federal oxidant standard.

Table 5-1. CITY-SPECIFIC EKMA PARAMETERS

Urban Area	Receptor Area	Date	O_3 Design Value (ppm)	O_3 Transport Value (ppm)
Bridgeport-New Haven, Connecticut	Eastford, Connecticut	May 24, 1977	0.190	0.154
Providence, Rhode Island	Medfield, Massachusetts	July 20, 1976	0.189	0.169
Boston, Massachusetts	West Newbury, Massachusetts	August 26, 1976	0.177	0.099
Springfield, Massachusetts	Greenfield, Massachusetts	August 5, 1976	0.169	0.126
Worcester, Massachusetts	Fitchburg, Massachusetts	July 27, 1976	0.130	0.125

Table 5-2. CALCULATED VOC EMISSION REDUCTIONS

Urban Area	0.08 ppm O_3 Standard			0.10 ppm O_3 Standard			0.12 ppm O_3 Standard		
	City-Specific EKMA	Standard EKMA	New England EKMA	City-Specific EKMA	Standard EKMA	New England EKMA	City-Specific EKMA	Standard EKMA	New England EKMA
Bridgeport-New Haven, Connecticut	72%	69%	70%	68%	67%	65%	60%	62%	59%
Providence, Rhode Island	72%	69%	69%	65%	66%	63%	59%	59%	56%
Boston, Massachusetts	71%	71%	71%	64%	69%	67%	61%	64%	63%
Springfield, Masachusetts	71%	68%	68%	66%	65%	63%	58%	59%	55%
Worcester, Massachusetts	61%	54%	54%	45%	40%	40%	24%	15%	19%

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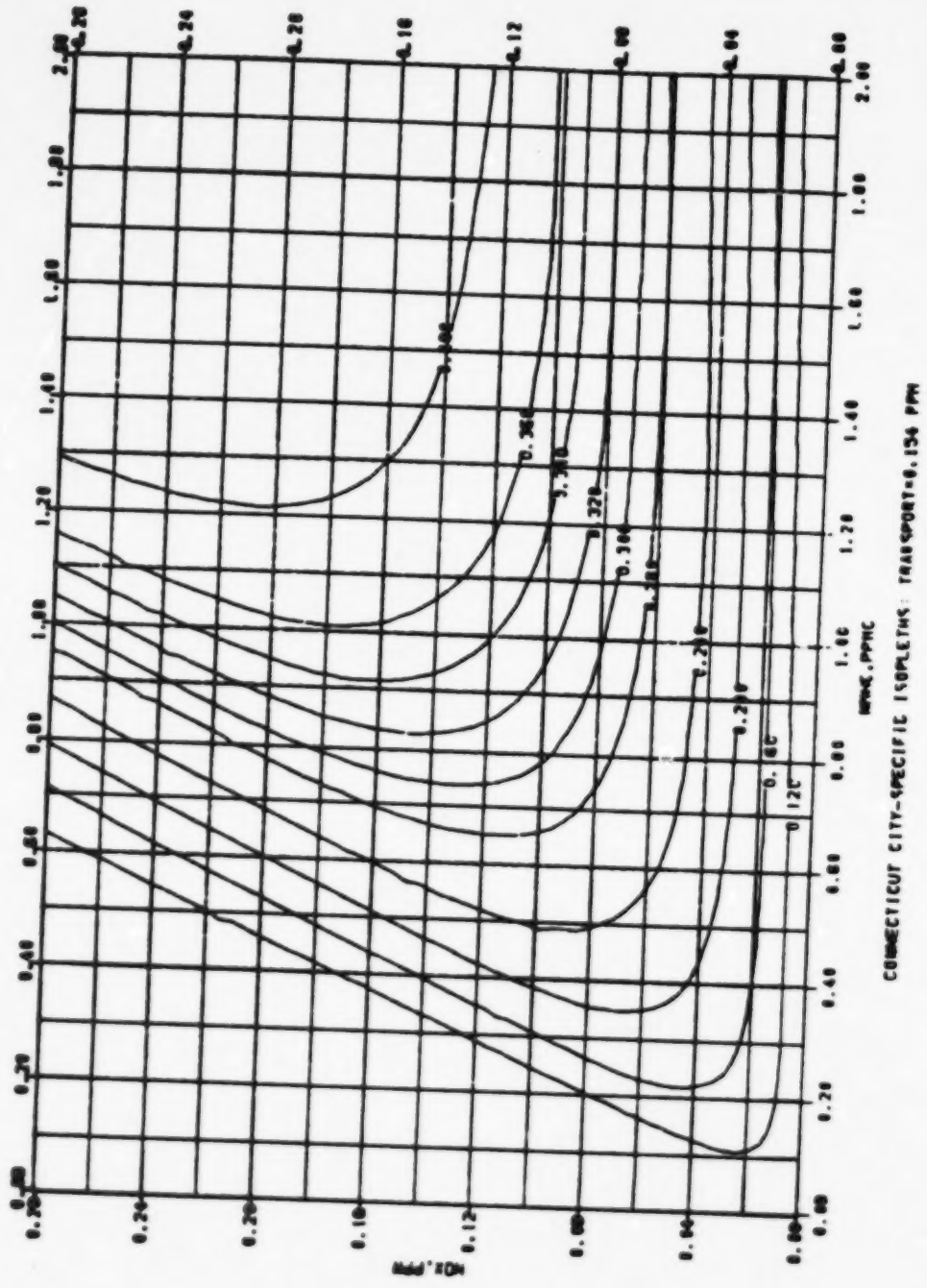
APPENDIX

CITY SPECIFIC OZONE ISOPLETH CURVES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CONNECTICUT CITY SPECIFIC ISOPLETHS: TRANSPORT=0.08 PPM

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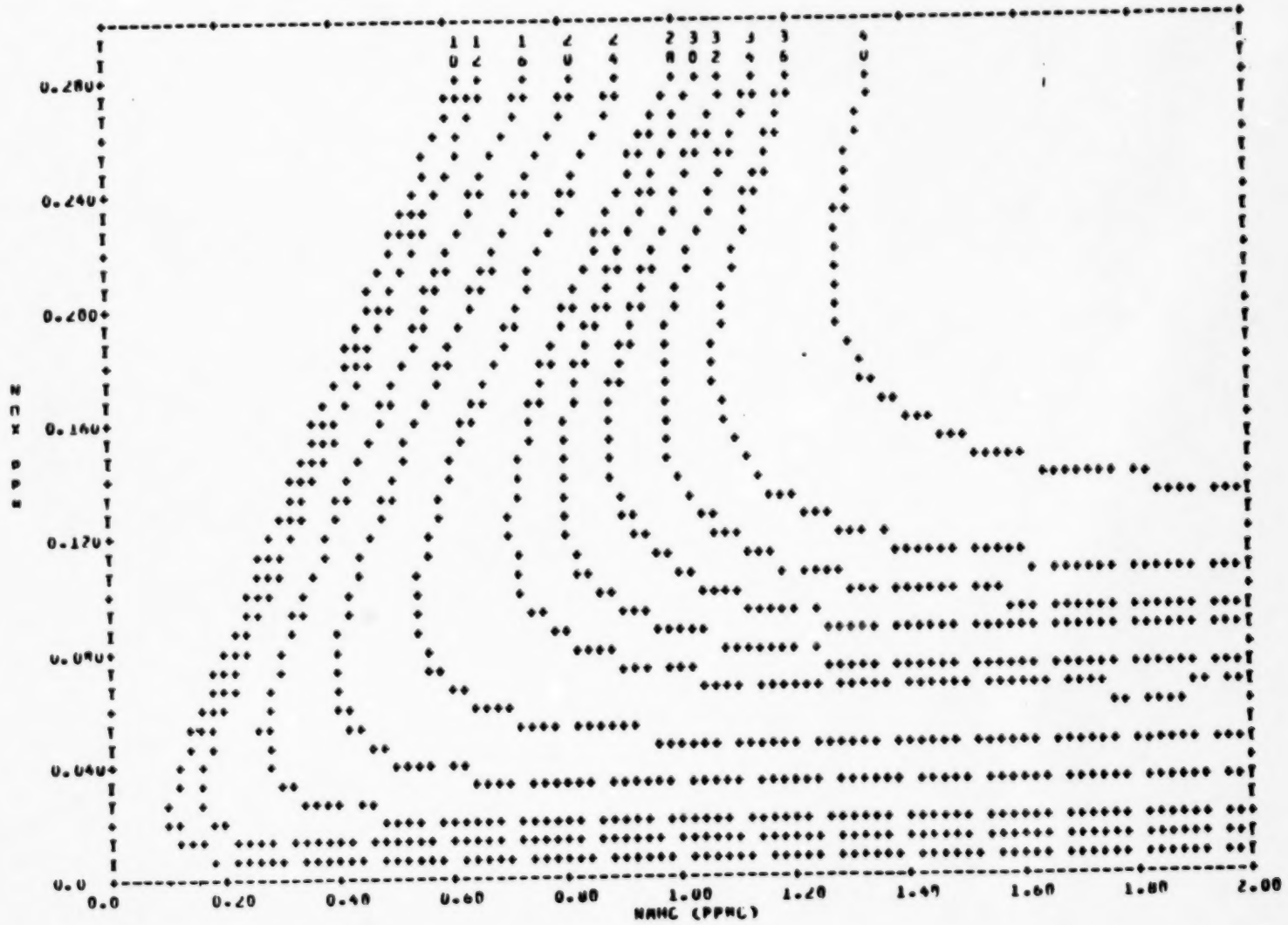
0.40000



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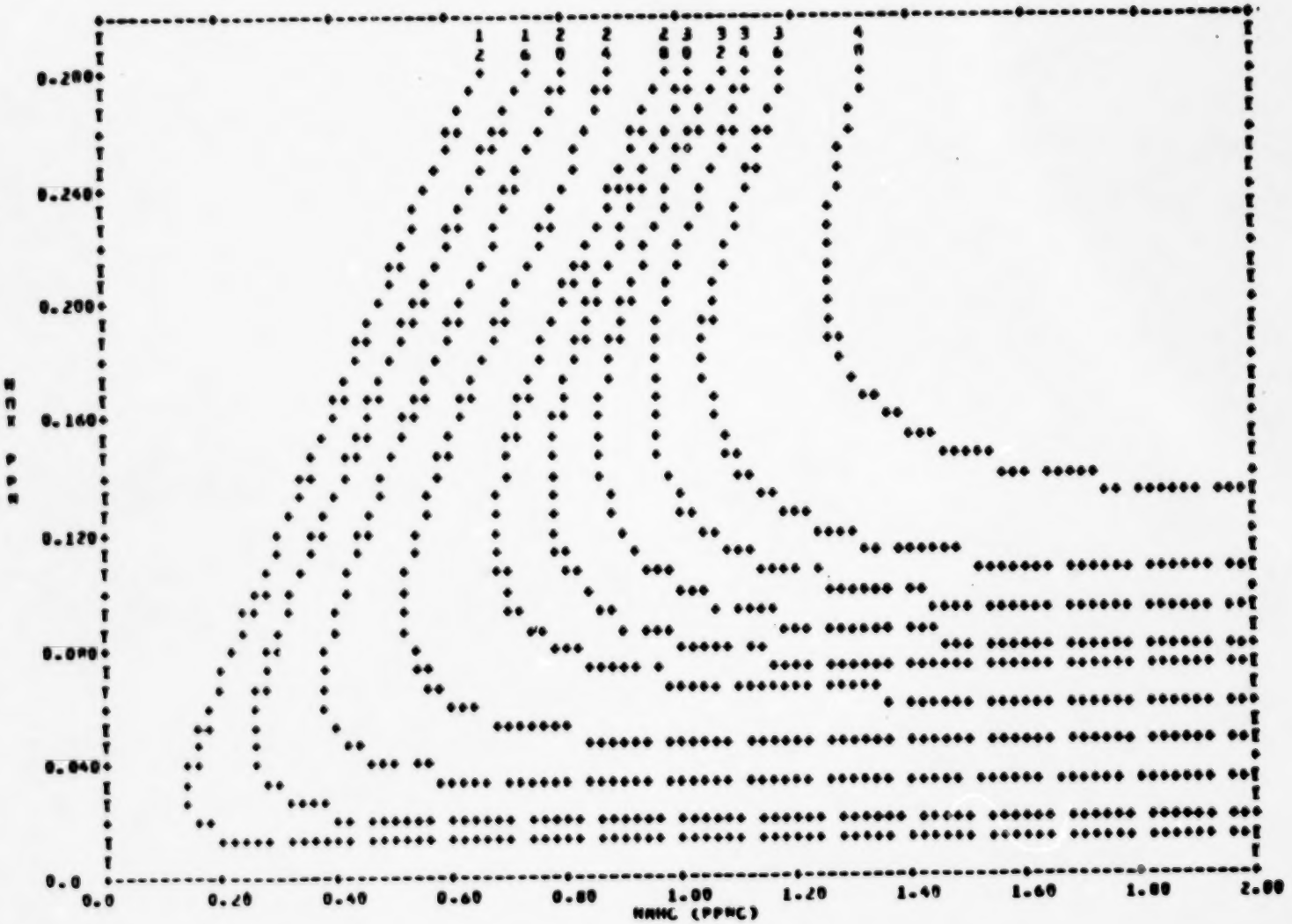

CONNECTICUT CITY SPECIFIC ISOPLETHS: TRANSPORT=0.12 PPM

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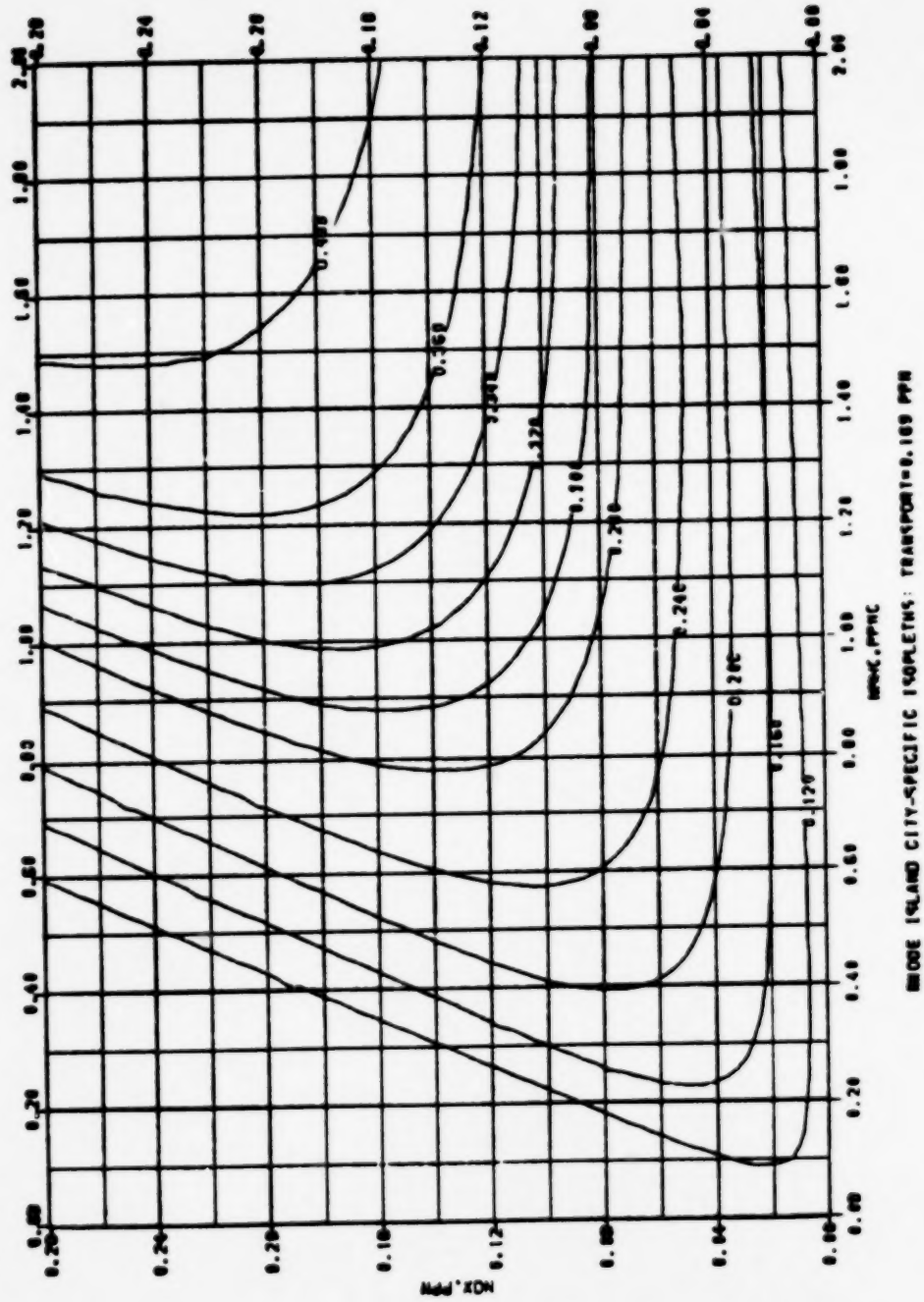
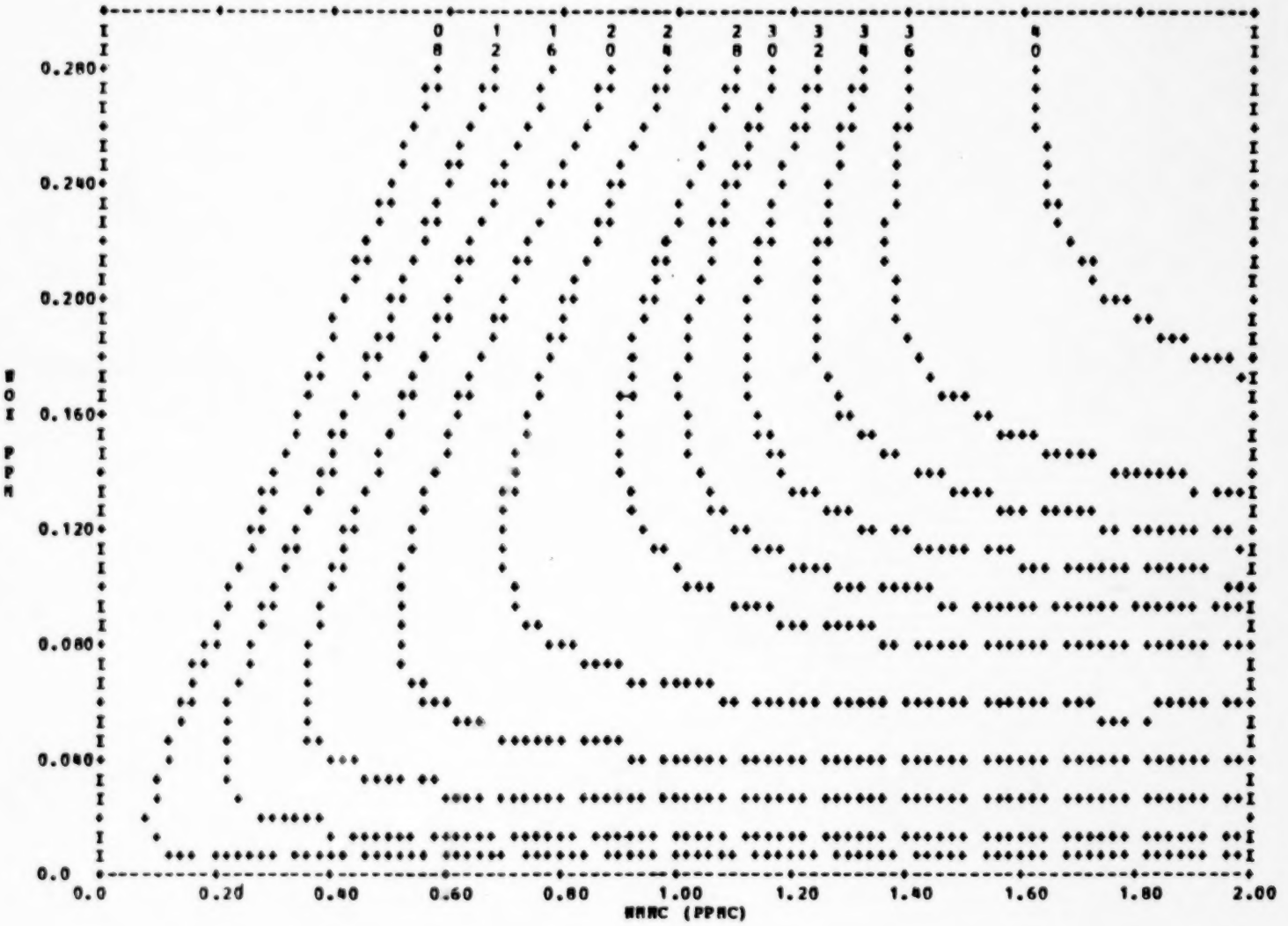

NOX, PPM
RHODE ISLAND CITY-SPECIFIC ISOPLETHS: TRANSPORT=0.169 PPM



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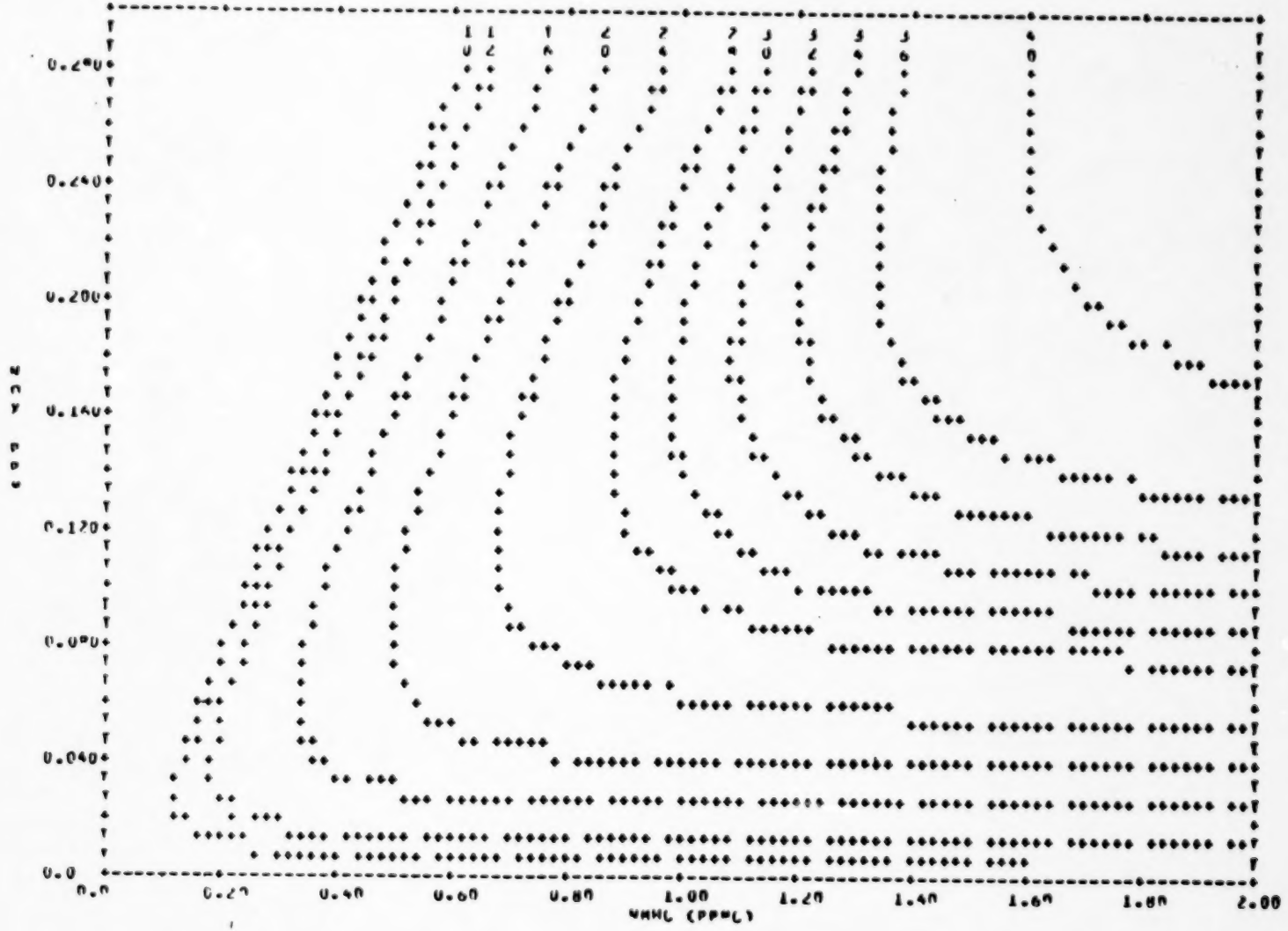

RHODE ISLAND CITY SPECIFIC ISOPLETHS: TRANSPORT=0.100 PPM

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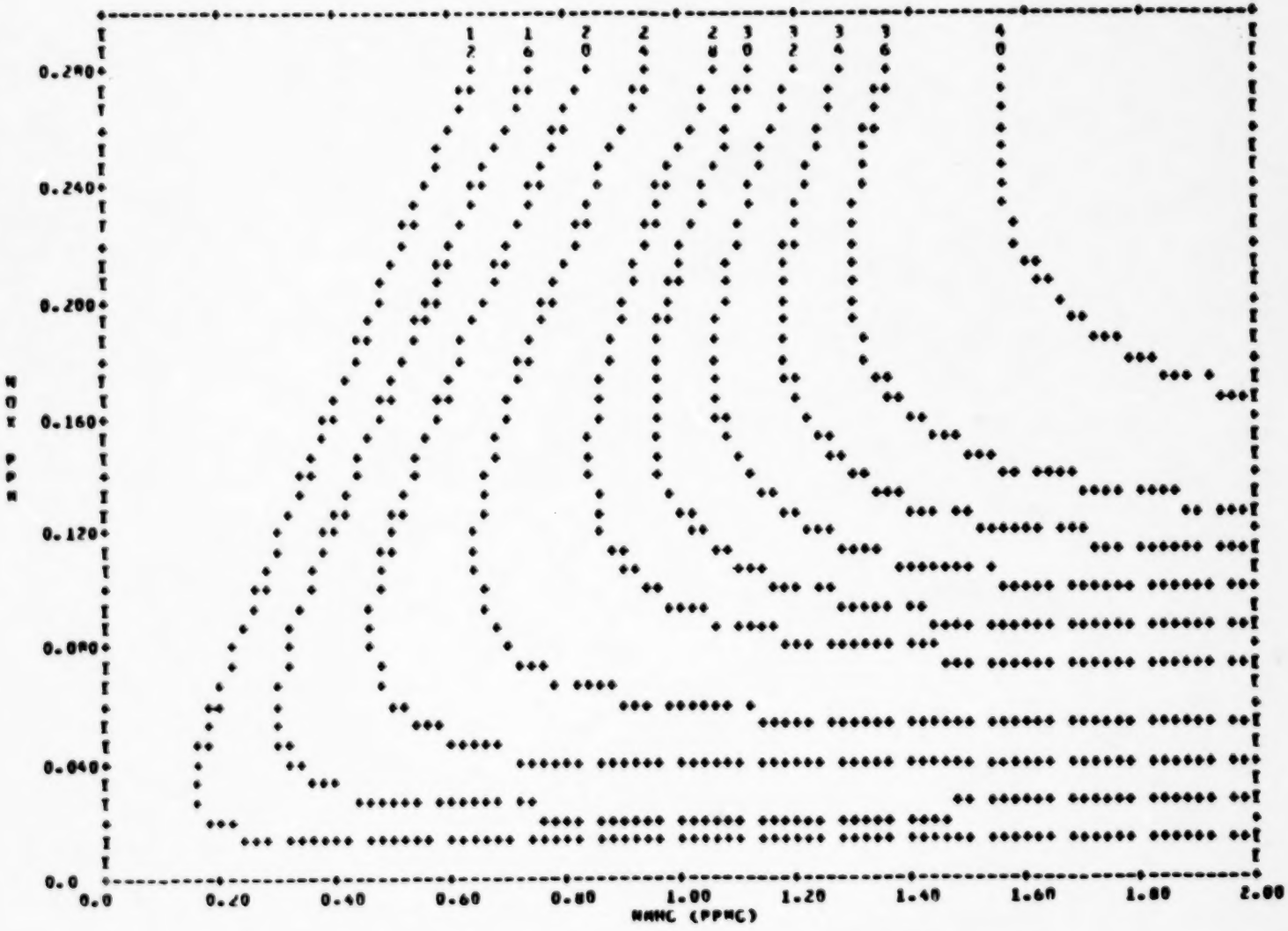

RHODE ISLAND CITY SPECIFIC ISOPLETHS: TRANSPORT=0.120 PPM

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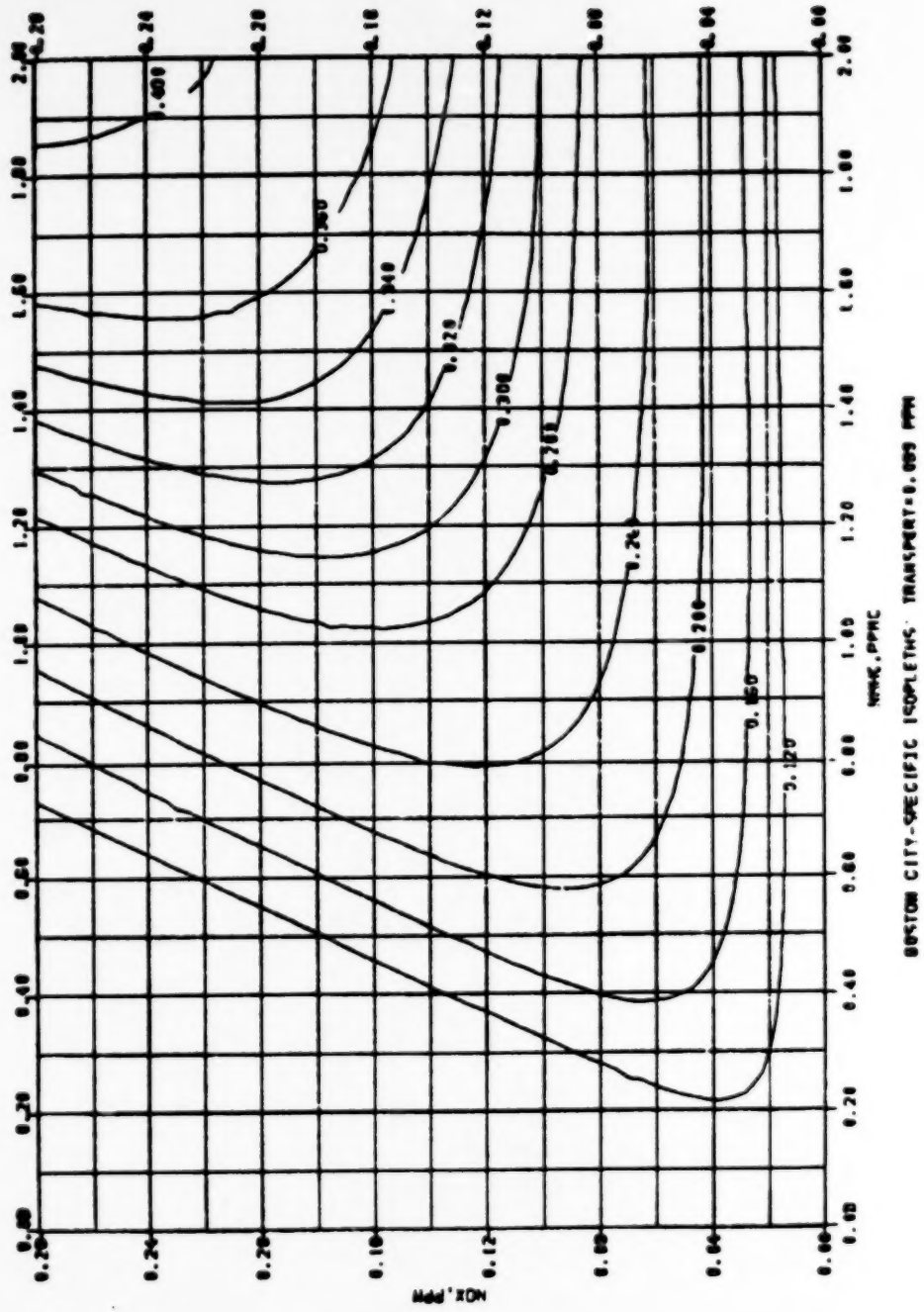
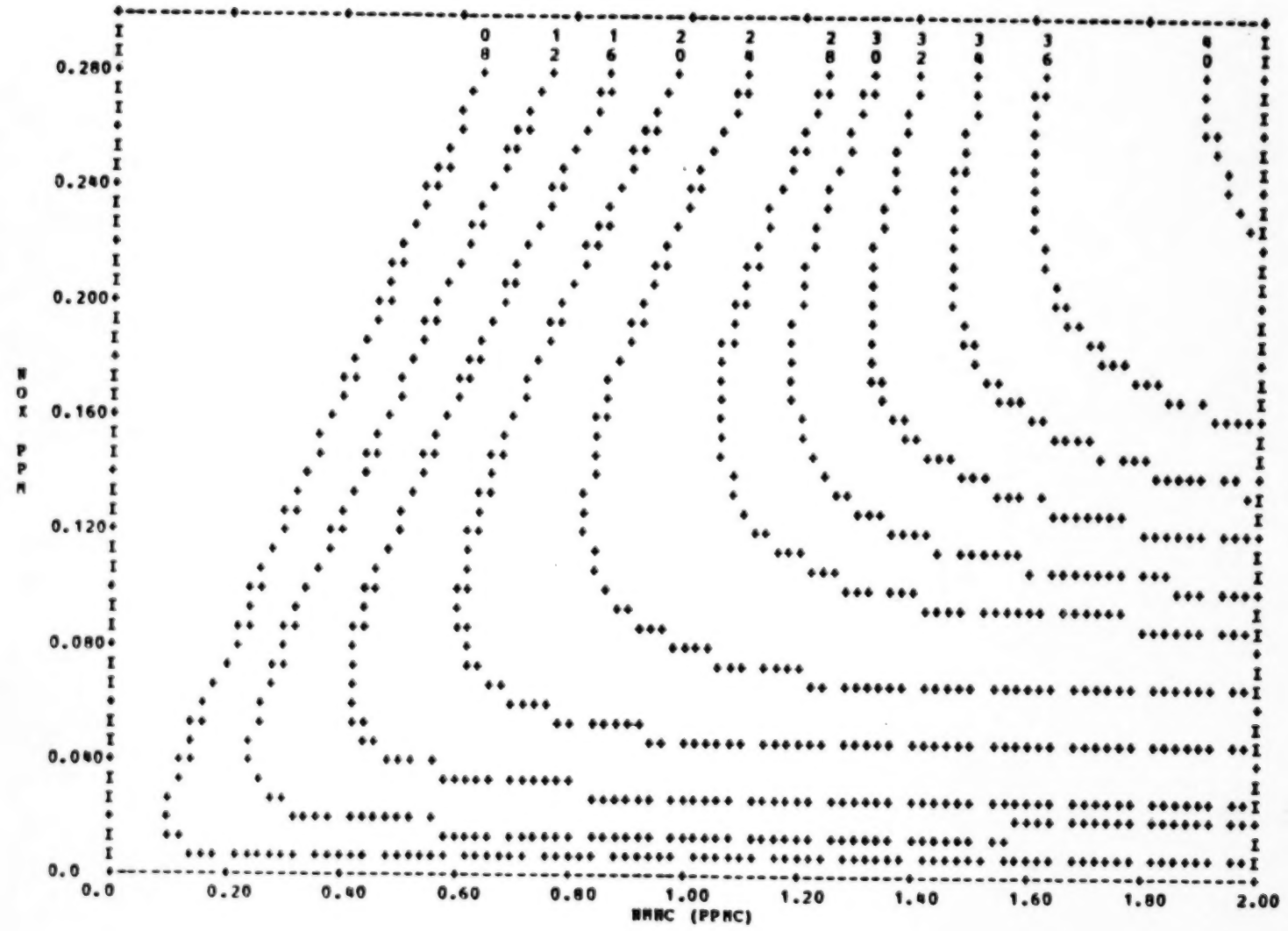


BOSTON CITY-SPECIFIC ISOPLETHS: TRANSPORT=0.000 PPM



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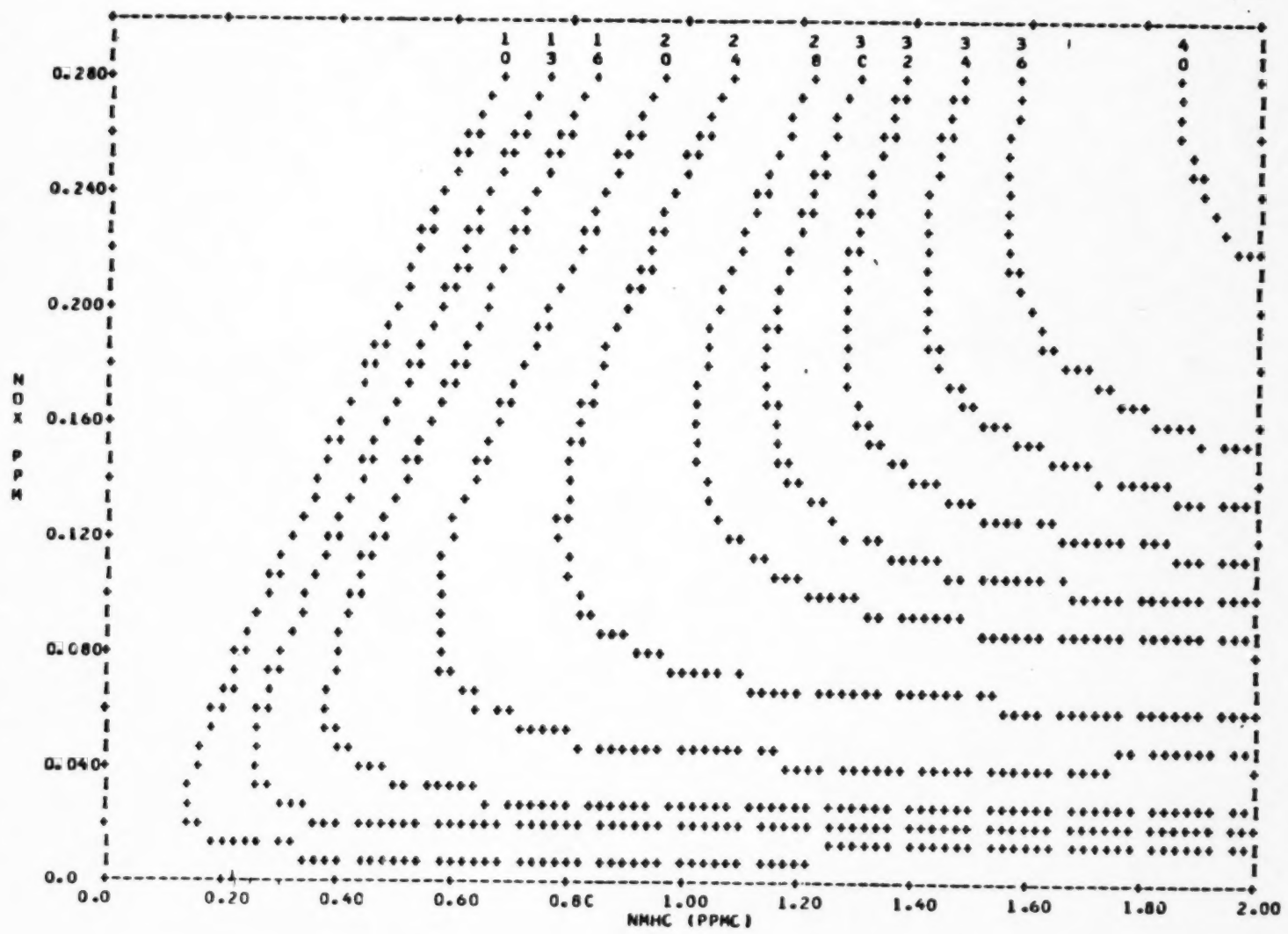
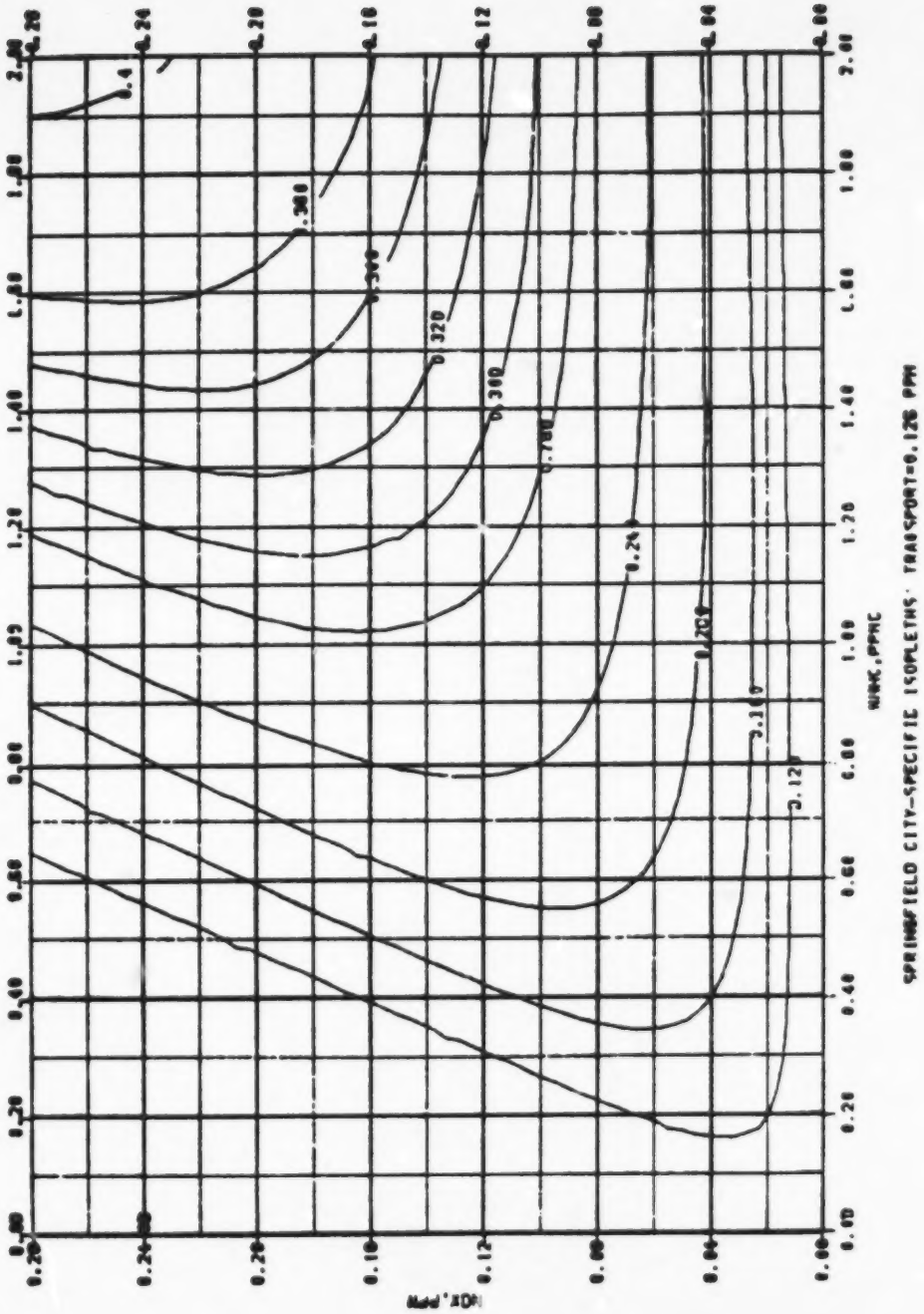


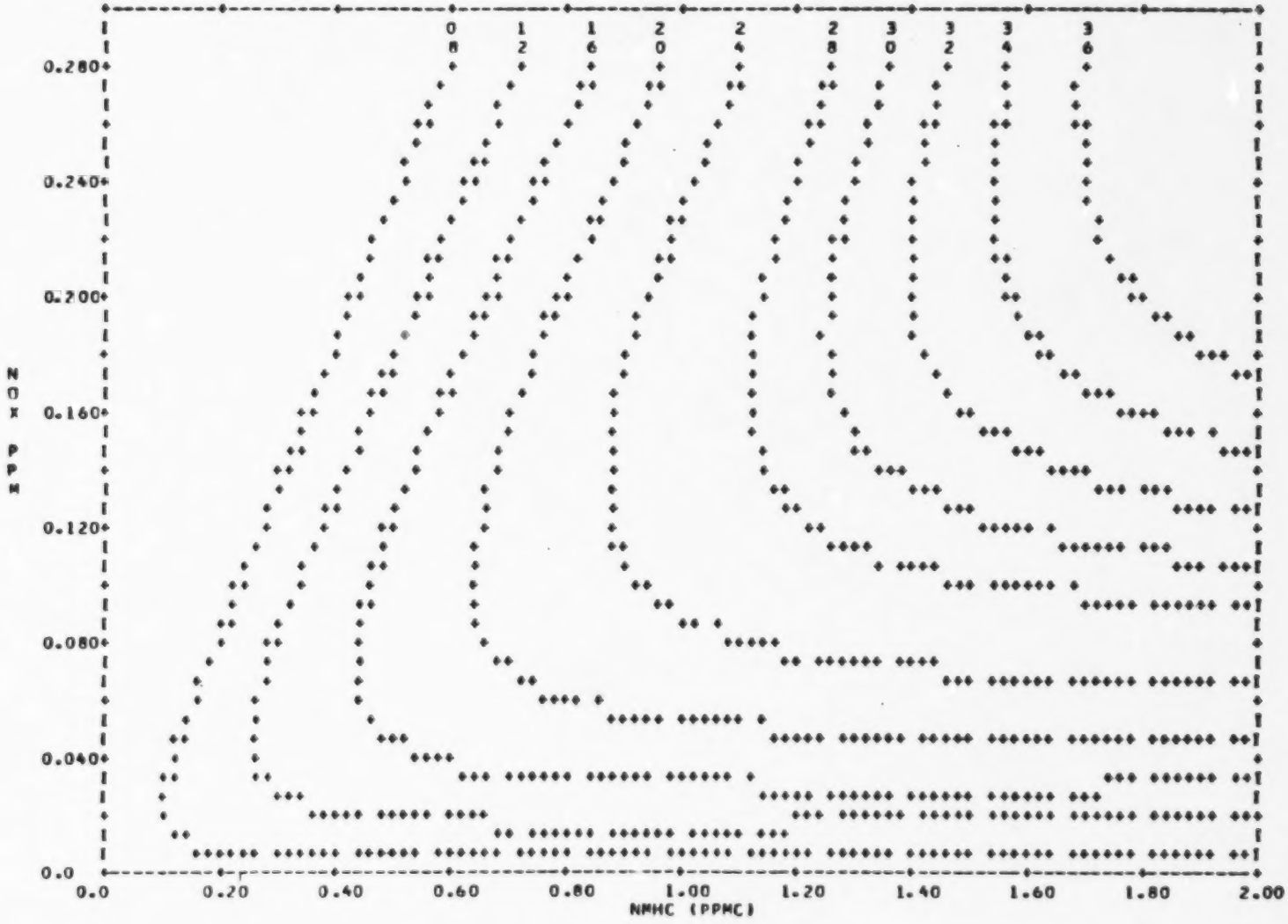
BOSTON CITY SPECIFIC ISOPLETHS: TRANSPORT=0.10 PPM

THE OZONE LINES ARE 0.10000 0.13000 0.16000 0.20000 0.24000 0.28000 0.30000 0.32000 0.34000 0.36000

A-11

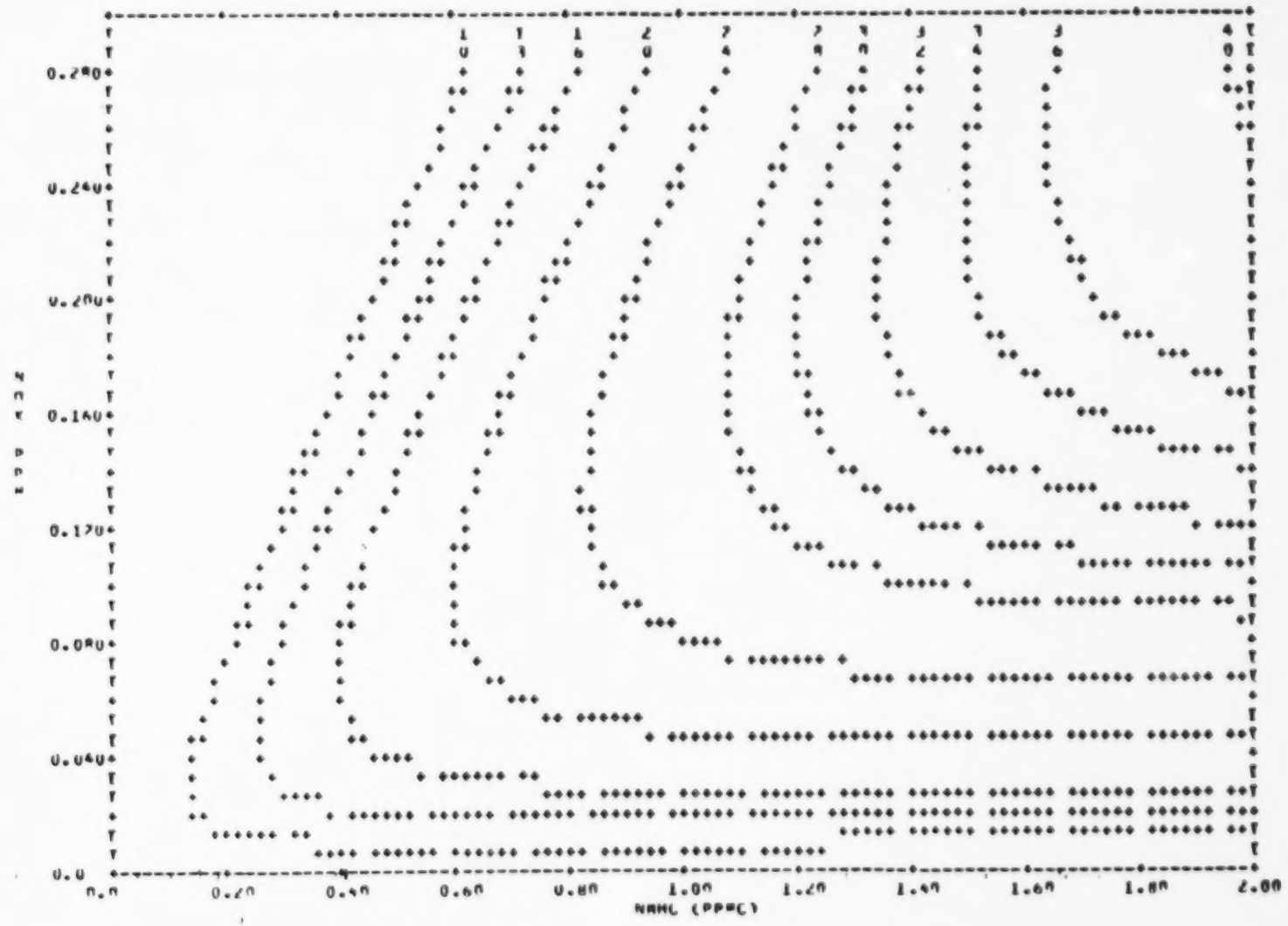


SPRINGFIELD CITY-SPECIFIC ISOPLETHS: TRANSPORT=0.125 PPM



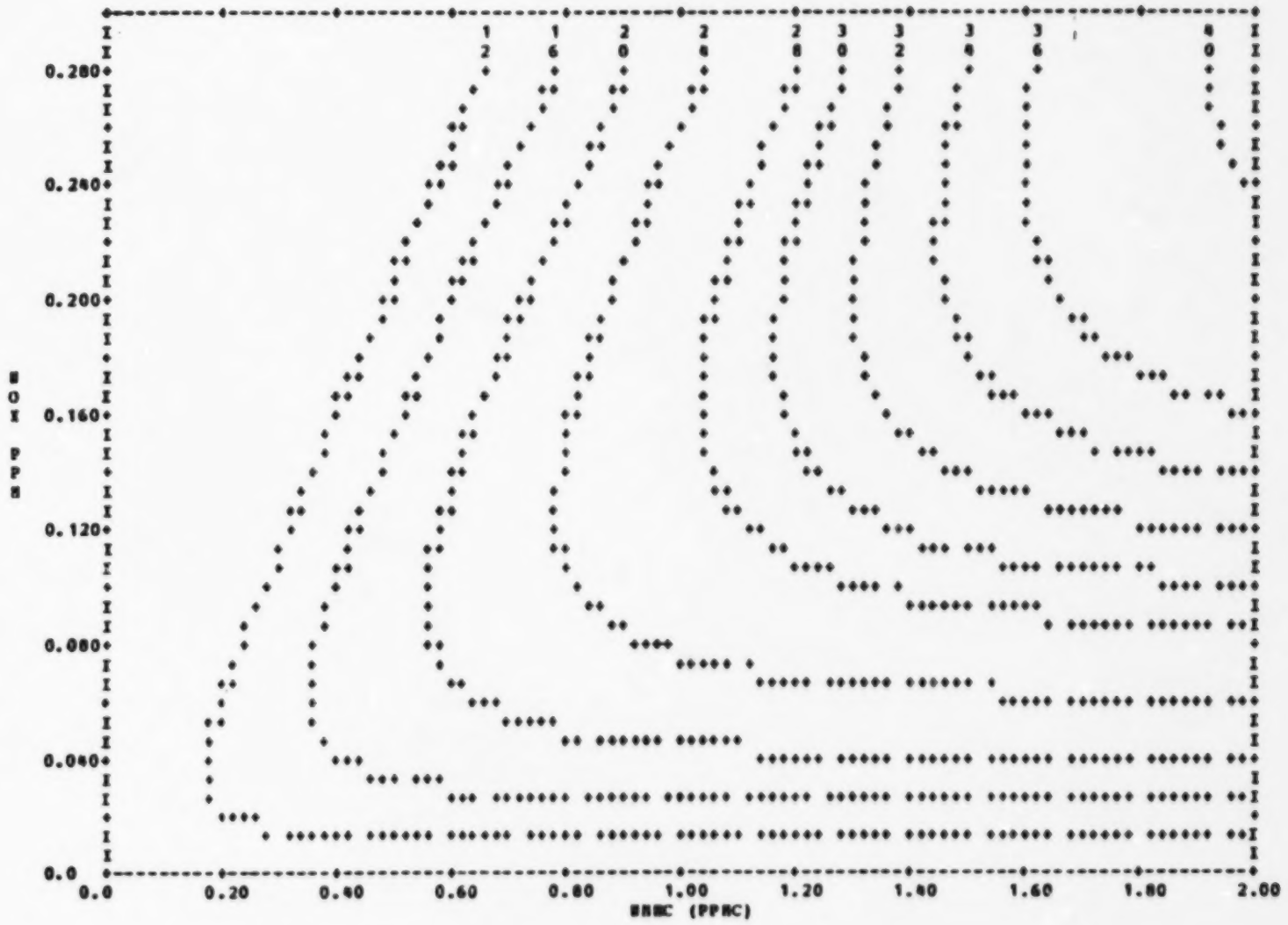
SPRINGFIELD CITY-SPECIFIC ISOPLETHS: TRANSPORT=0.080 PPM

THE OZONE LINES ARE 0.08000 0.12000 0.16000 0.20000 0.24000 0.28000 0.30000 0.32000 0.34000 0.36000



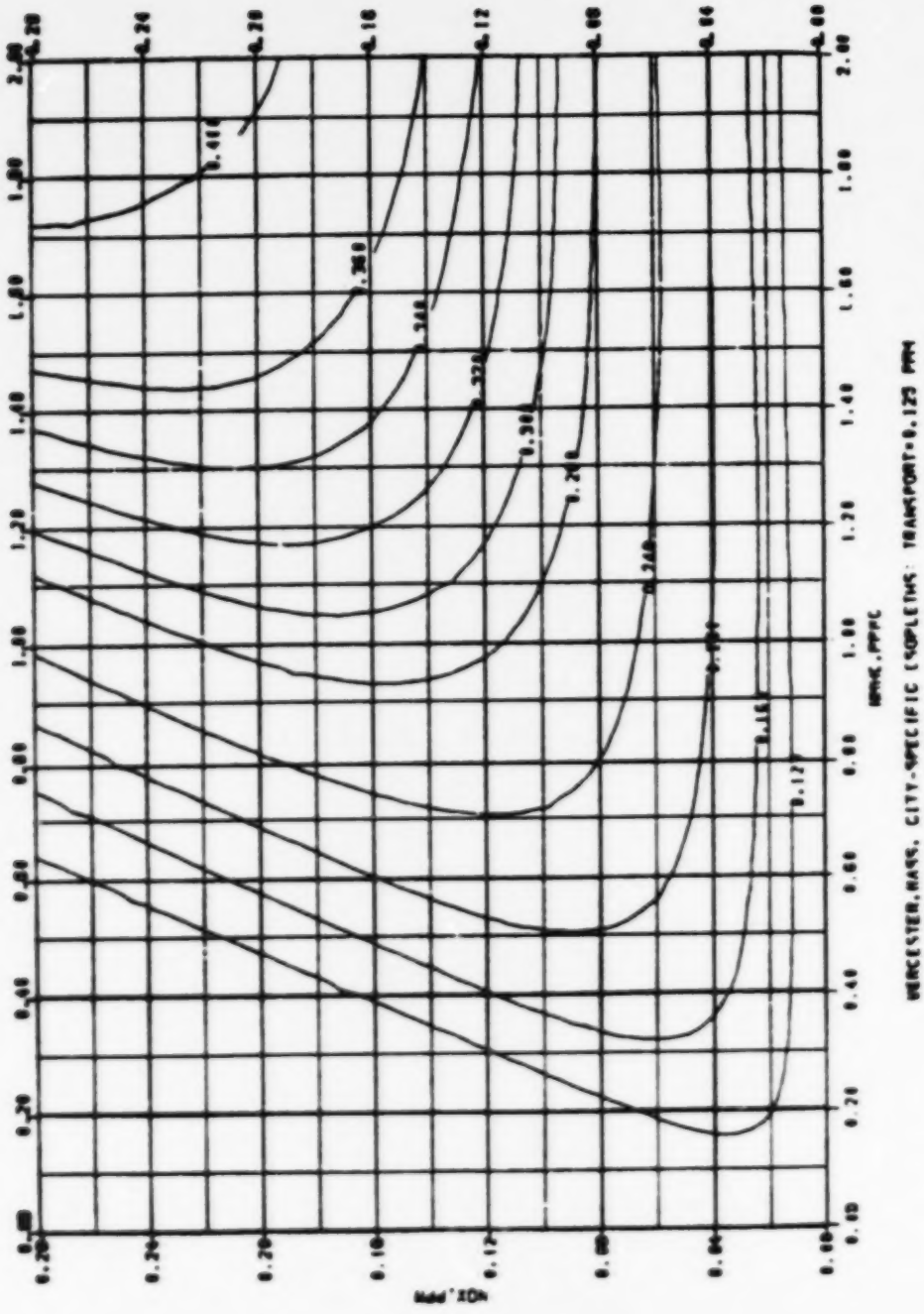
SPRINGFIELD CITY-SPECIFIC ISOPLETHS: TRANSPORT=0.100 PPM

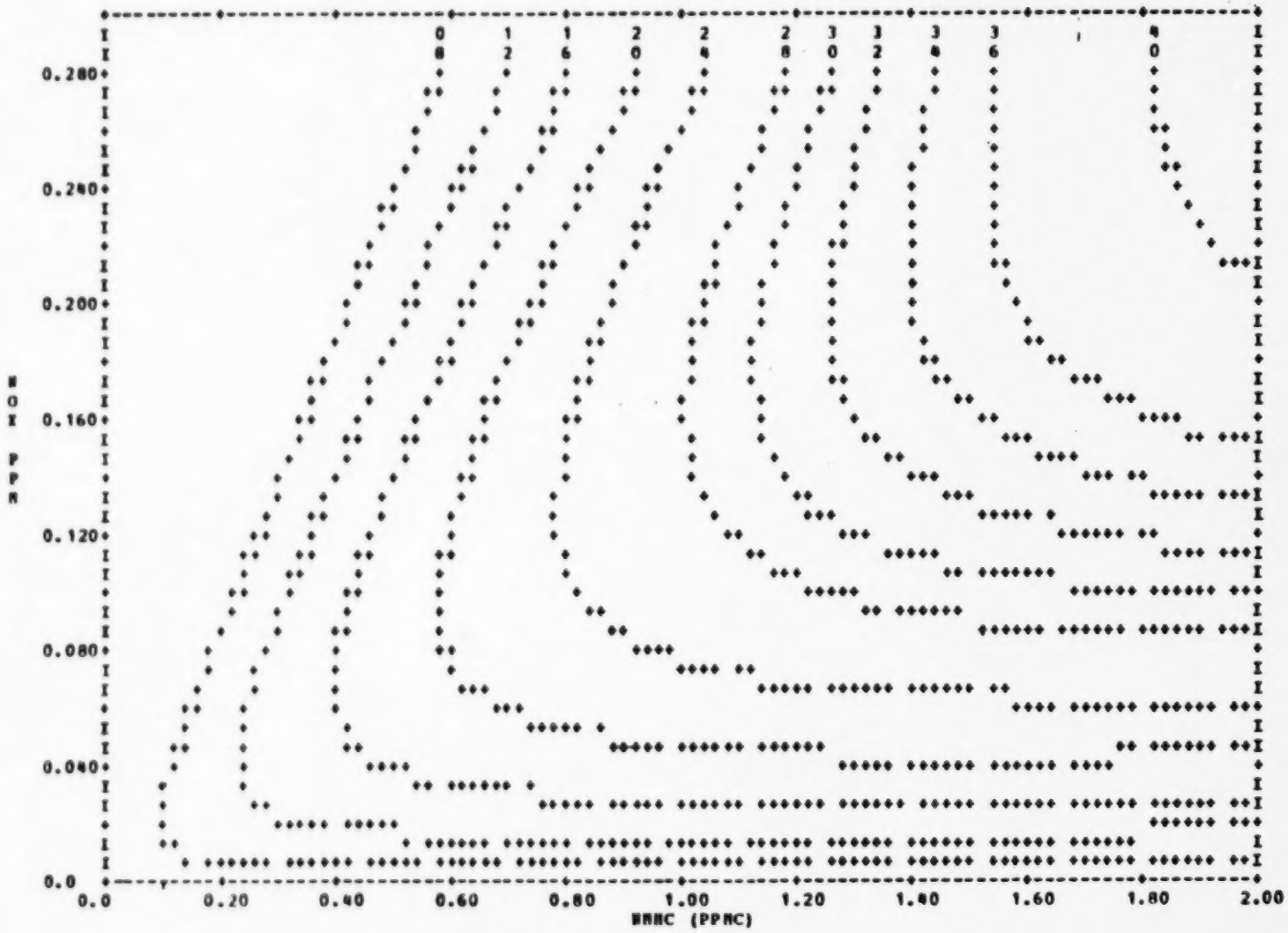
THE OZONE LINES ARE 0.10000 0.13000 0.16000 0.20000 0.24000 0.29000 0.30000 0.37000 0.34000 0.34000
0.40000



SPRINGFIELD CITY-SPECIFIC ISOPLETHS: TRANSPORT=0.120 PPM

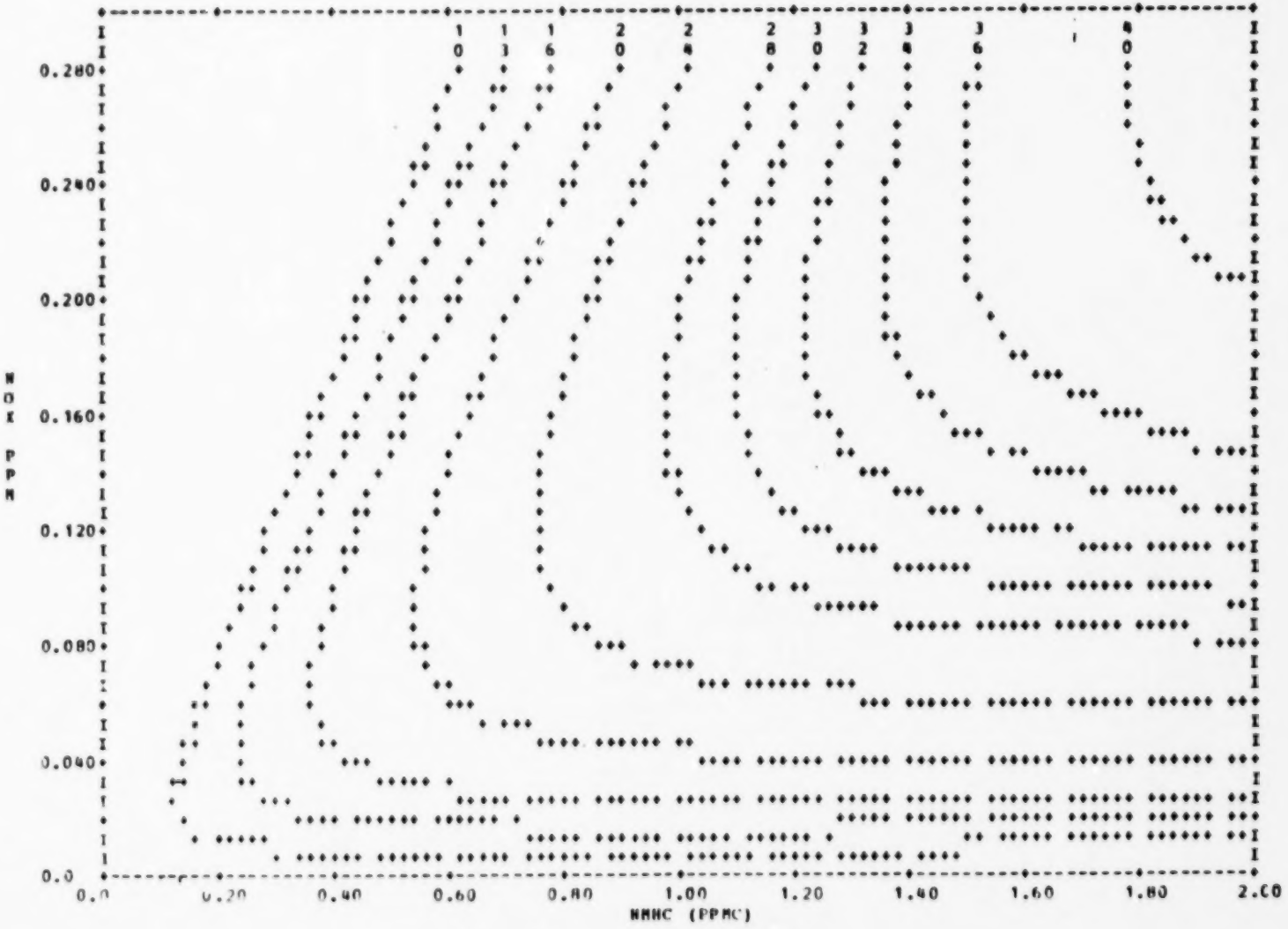
THE OZONE LINES ARE 0.12000 0.16000 0.20000 0.24000 0.28000 0.30000 0.32000 0.34000 0.36000 0.40000


WORCESTER, MASS. CITY-SPECIFIC (SUPPLEMENT: TRANSPORT=0.125 PPM
NOX, PPM
HC, PPMC



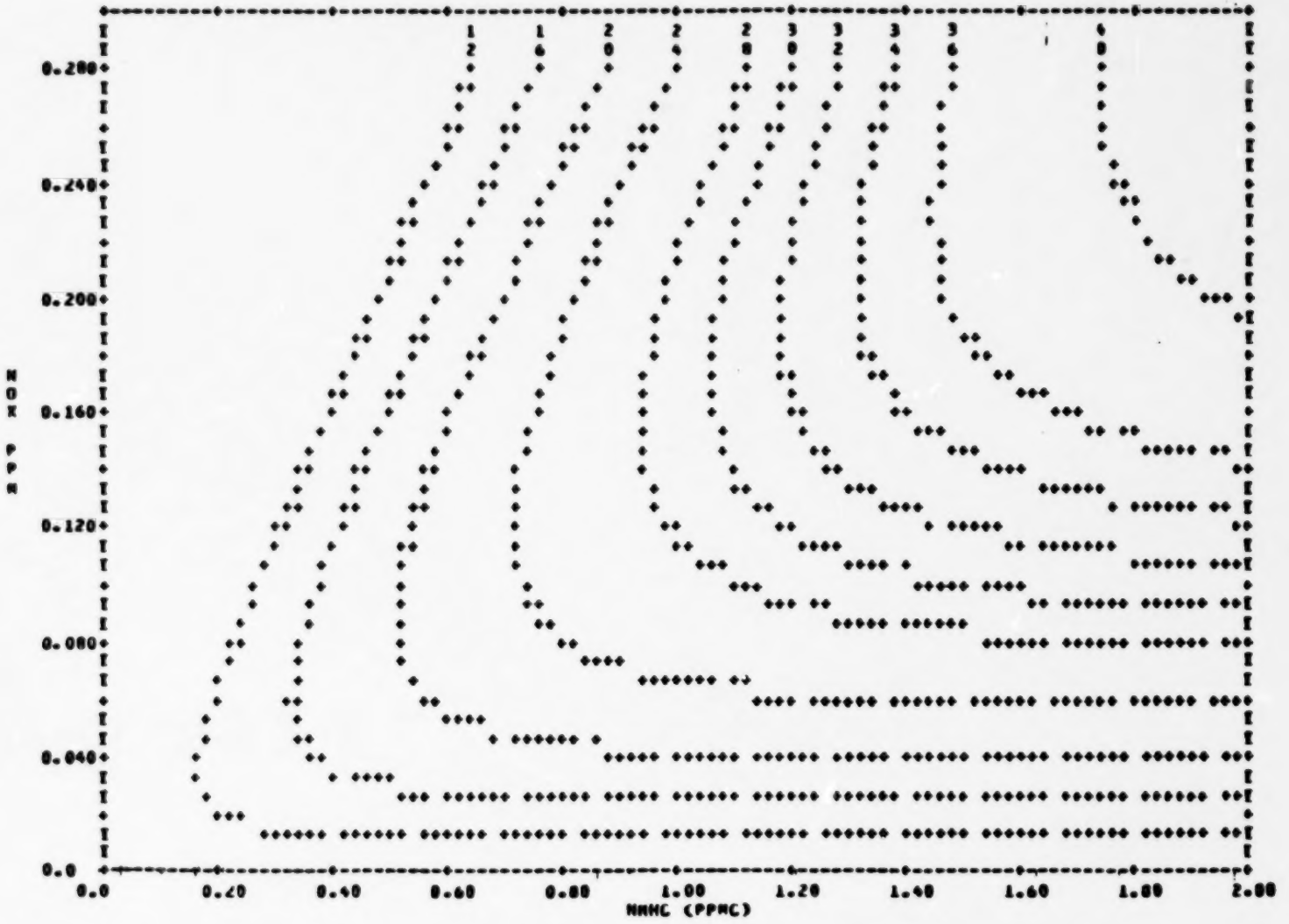
WORCESTER CITY SPECIFIC ISOPLETHS: TRANSPORT=0.080 PPM

THE OZONE LINES ARE 0.08000 0.12000 0.16000 0.20000 0.24000 0.28000 0.30000 0.32000 0.34000 0.36000



Worcester, Massachusetts City Specific Isopleths: Transport=0.100 ppm

THE OZONE LINES ARE 0.10000 0.13000 0.16000 0.20000 0.24000 0.28000 0.30000 0.32000 0.34000 0.36000



WORCESTER CITY SPECIFIC ISOPLETHS: TRANSPORT=0.120 PPM

THE OZONE LINES ARE 0.12000 0.16000 0.20000 0.24000 0.28000 0.30000 0.32000 0.34000 0.36000 0.40000